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JPRS L/8602

2 August 1979

# USSR Report

## GEOPHYSICS, ASTRONOMY AND SPACE

(FOUO 3/79)

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2 August 1979

# USSR REPORT

## GEOPHYSICS, ASTRONOMY AND SPACE

(FOUO 3/79)

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CONTENTS PAGE

I. METEOROLOGY

Translation

UDC 550.7:574.9(267)"313": A. A. Grigor'yev (092)

FUTURE OF THE BIOSPHERE

Moscow IZVESTIYA AKADEMII NAUK SSSR, SERIYA GEOGRAFICHESKAYA in Russian No 3, 1979 pp 30-39

[Article by M. I. Budyko, State Hydrological Institute]

[Text] Global warming. Several years ago there were only individual scientists who expressed the opinion that as a result of an increase in the quantity of carbon dioxide in the atmosphere under the influence of man's economic activity a global warming is developing. During recent years, however, this point of view has become widely accepted. At scientific conferences held in West Berlin (1976), Tokio (1976), Miami (1977), Ratzeburg (1977), Vienna (1978) and Dushanbe (1978) those present presented materials making it possible to draw the conclusion that there would inevitably be a change in global climate in the direction of a warming if in the future there was persistence of the present-day trends in the development of electric power based on the combustion of coal, petroleum and other types of fossil fuel.

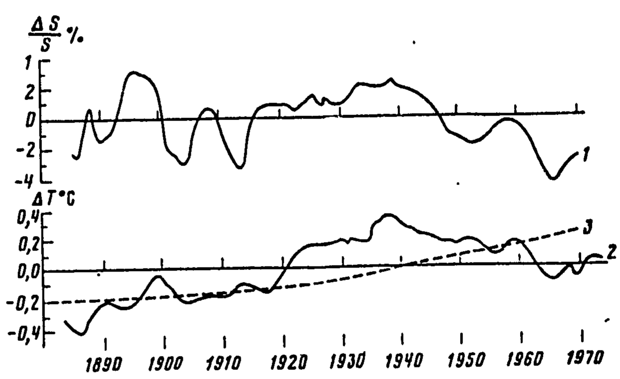


Fig. 1. Secular variation of air temperature and variations of atmospheric transparency.

There is basis for assuming that an anthropogenic warming has already been occurring over a period of years and the rate of this warming is increasing. Figure 1 shows data characterizing the changes in the mean air temperature at the surface in the northern hemisphere, computed for moving five-year intervals (curve 1) and the results of computation of the change in this temperature under the influence of an increase in the quantity of carbon dioxide (curve 2) during the last 90 years. It can be seen that although the actual temperature changes differ from the results of computations, observational data confirm the presence of a tendency to an increase in temperature in the second segment of the considered period in comparison with its first segment. In particular, whereas up to 1920 the temperature did not once attain the mean value for the entire period (norm), after this year, except for a relatively short time interval, it was above the norm. The reason for the noncoincidence of curves 1 and 2 is clear: their difference is attributable to the influence exerted on air temperature by variations in atmospheric transparency. It was established that with decreases in transparency the temperature increases, whereas with an increase the transparency decreases. This pattern is confirmed by a comparison of data, characterizing atmospheric transparency, on the relative values of the solar radiation anomaly in a cloudless sky, computed for a group of actinometric stations (curve 3), with the secular variation of air temperature (curve 1).

It can therefore be concluded that as a result of the increase in the concentration of carbon dioxide (which during the last century increased by 12-13%) the mean air temperature at the earth's surface increased by approximately 0.5°. Although this is not a small value, for the time being it is masked to a considerable degree by short-period climatic variations associated with changes in atmospheric transparency. However, available computations show that in the course of the next few decades the increase in the concentration of carbon dioxide will lead to a far greater change in mean air temperature, which will attain several degrees (Budyko, 1972, 1977). In this case the natural changes in the thermal regime, caused by variations in atmospheric transparency, will be far less than the anthropogenic change in climate. Evidently, under such conditions there will be not only a change in climate, but also all the components of the environment dependent on the state of the atmosphere.

In the investigation of evolution of the biosphere caused by man's influence on global climate it is possible to apply the concept of a physiographic process proposed in the well-known works of A. A. Grigor'yev and set forth most fully in the collection of his papers on problems relating to the theory of physical geography (Grigor'yev, 1966). According to this concept, the physiographic process stands out as a complex of processes forming the external geographic shell of the earth. For areas of considerable extent the key link in the physiographic process is assumed by A. A. Grigor'yev to be climate, whose changes determine the state of the remaining components. The scientist established a correlation between the climatic factors characterizing the heat and moisture regimes and the intensity of such natural processes as productivity of the vegetation cover, soil formation, erosion, etc. He made clear the importance of productivity of the plant cover as an indicator characterizing the physiographic process as a whole. Such an idea was evidently related to the decisive importance of the productivity of autotrophic plants for the energy balance of almost the entire mass of living organisms in the biosphere, which exert an enormous influence on the state and evolution of the earth's outer geographic shell.

The change in the environment which is now occurring, caused by the restructuring of global climate, can be regarded as a special case of the development of the physiographic process, developments affecting all components of the outer geographic shell.

Atmospheric composition and climate. For a better understanding of the regularities in the present-day change in the chemical composition of the atmosphere, in an investigation by the author, A. B. Ronov and A. L. Yanshin a study was made of the evolution of the atmosphere over the course of the Phanerozoic. In particular, it was established in this study (for a brief exposition of this study see Budyko, 1977a) it was established that from late in the Cretaceous there was a predominance of a tendency to a decrease in the quantity of carbon dioxide in the atmosphere, as a result of which during the last 100 million years the $CO_2$ concentration decreased by several times. The left side of Fig. 2 gives the $CO_2$ concentrations found in that study for different parts of the Tertiary; the straight line characterizes the mean dependence of the $CO_2$ concentration on time. At the right of the figure, at a far greater time scale, we have shown data on the change in $CO_2$ concentration after 1900. The upper and lower curves in this graph correspond to the results of computations made by Keeling for extreme variants of development of power in the future (ENERGY AND CLIMATE, 1977).

By comparing the right and left sides of the graph it is easy to see that after a relatively slow increase in the concentration of $CO_2$ in the 20th and 21st centuries the mass of $CO_2$ should increase rapidly, attaining values characteristic for the Tertiary atmosphere. The reason for the enormous rate of restoration of the ancient composition of the atmosphere is that in the course of present-day economic activity during each decade there is combustion of supplies of coal, petroleum and fuel gases which were created over the course of millions of years. It has been established that about half the quantity of carbon dioxide formed during the combustion of fossil fuel is retained in the atmosphere and this is leading to a rapid change in its chemical composition.

In order to evaluate the climatic conditions which arise with a change in the chemical composition of the atmosphere it is possible to employ two independent methods. One of them is based on the use of models of the theory of climate, making it possible to compute the elements of the meteorological regime with a stipulated quantity of carbon dioxide in the atmosphere. Another approach is associated with the use of paleoclimatic data relating to epochs with a higher concentration of atmospheric carbon dioxide. For this purpose it is best to use data on the climate of the Neogene, when the quantity of carbon dioxide in the atmosphere corresponded to the level of its concentration which should be attained in the 21st century. At the same time, in the Neogene the external climate-forming factors (structure of relief, position of the earth's poles, solar constant) differed little from the present-day epoch.

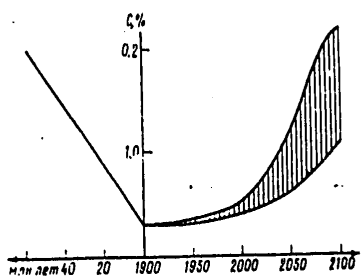


Fig. 2. Changes in $CO_2$ concentration in atmosphere. Along x-axis: millions of years

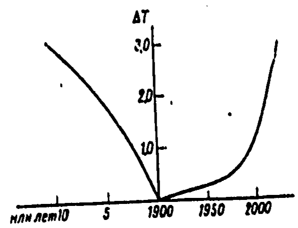


Fig. 3. Changes in mean air temperature at earth's surface. Along x-axis: millions of years

Figure 3 shows the results of computations of changes in mean air temperature at the earth's surface for the Neogene (left part of graph) and for the 20th-21st centuries (right part). The $\Delta T$ values shown on the graph correspond to the difference between the mean temperature for different moments in time and its value for the onset of the 20th century. These values for the Neogene were found both on the basis of paleoclimatic data and on the basis of computations when using models of climatic theory. The results were in very good agreement. For the end of the 20th century and the 21st century the $\Delta T$ values were also computed by two methods: on the basis of model computations and using the empirical dependence between $\Delta T$ and the carbon dioxide concentration, which gave results which coincided. It can be seen that already in the first quarter of the 21st century the mean temperature at the earth's surface attains a level characteristic for the Pliocene, after which it will continue to rise.

Model computations and paleoclimatic data show that an increase in mean temperature under the influence of the increase in the $CO_2$ concentration differs substantially in dependence on latitude. In the high latitudes this increase is several times greater than in the low latitudes. Therefore, in the case of anthropogenic change in climate the greatest changes in natural conditions will occur in the high and in part in the middle latitudes. A detailed description of climatic changes with an increase in the concentration of carbon dioxide for Europe and the extratropical territory of Asia was given in a recently published study (Budyko, et al., 1978).

Ice cover. The melting of polar sea ice caused by global warming can be of substantial importance for the natural conditions of the future.

The area occupied by sea polar ice and its mean thickness are determined for the most part by climatic conditions. In earlier studies a numerical model based on the equations for the heat and water balances of ice was proposed. Its use made it possible to compute the present-day boundaries of sea ice and its thickness. The results agreed satisfactorily with observational data (Budyko, 1969, 1971). It follows from the computations based on use of this model that the ice regime is dependent on the receipt of solar radiation, air temperature in the warm season of the year (during the season of ice melting) and air temperature during the cold period, when the ice thickness increases primarily as a result of freezing of the water at its lower surface. The computations made indicated that the ice thickness changes considerably when there are relatively small changes in air temperature during the warm season, since the influence of temperature variations during the cold season is considerably weaker.

Using the data from these computations, it can be estimated when the perennial ice in the Central Arctic will be transformed into one-year ice as a result of an increase in the global warming.

It follows from empirical data on present-day climatic changes that during the warming an increase in temperature in the zone of sea arctic ice during the summer on the average is equal to about 75% of the increase in mean temperature for the northern hemisphere, whereas during winter it exceeds this increase by a factor of 4-5. Accordingly, an increase in the mean temperature of the hemisphere by 2° corresponds to a warming in the zone of sea ice by 1.5° in summer and 8-10° in winter.

Computations made using the theory mentioned above show that under such conditions the mean thickness of the ice during summer decreases by more than 3 m. This is adequate for transforming perennial ice into one-year ice, after which there should be development of additional warming caused by a decrease in the albedo of the earth's surface in the high latitudes. Since in a number of investigations the conclusion was drawn that there can be an ice-free regime in the Central Arctic even in the absence of anthropogenic heating of the atmosphere (Budyko, 1971) it is probable that in the presence of such heating after the melting of the perennial ice one-year ice will either disappear or will appear only in the coastal regions of the Arctic Ocean with the coldest winters.

In addition to the semiempirical method used here for evaluating the influence of melting of sea ice in the development of warming it is possible to have a purely empirical solution of this problem.

We take into account that the perennial ice in the Arctic exists with an air temperature in the warmest month from -1 to +2°. Most of the ice is in a zone with the temperature of the warmest month from 0 to +2°.

In investigations of changes in climate it was established that during a warming the increase in air temperature near the boundary of sea ice is somewhat greater than the mean temperature change over the entire zone of the ice cover and according to empirical data for the summer season is about 100% of the mean increase in temperature for the northern hemisphere.

In this connection, if the mean temperature for the hemisphere increases by 2°, the perennial ice in the zone with a temperature of the warmest month from 0 to +2° should melt first in the peripheral part of this zone, where the temperature increase will be greatest, and then also in the central regions. Evidently, as the ice melts the air temperature in those regions where for the warmest month it is not much below 0° is increased due to additional warming caused by a decrease in the albedo of the earth's surface. This leads to a total melting of the ice. Taking into account that the mean air temperature has already increased by several tenths of a degree in comparison with the end of the last century, and taking into account the possible error in computations, it must be surmised that for the thawing of perennial sea ice in the Arctic it is sufficient that there be a temperature increase by 2-3° relative to the preindustrial era. Such a temperature increase can be attained by the year 2025. It is evident that the time of ice melting can vary due to the acceleration or slowing of the process of warming as a result of variation in atmospheric transparency.

Due to a decrease in the albedo of the earth-atmosphere system after thawing of the ice there will be an additional temperature increase, especially significant in the high latitudes. Taking into account the results of computations of air temperature in the case of the ice-free Arctic (Budyko, 1971) and taking into account the data cited above on the influence of an increase in the mass of carbon dioxide on the thermal regime, it can be concluded that by the year 2025 the air temperature will increase in the high latitudes in summer by 10-15°, and in winter by 15-20°. Such changes in the thermal regime will exert an enormous influence on natural conditions.

A problem which merits attention is the possibility of partial destruction of the western part of the antarctic glacier under the influence of a warming. This will lead to an increase in the level of the world ocean by several meters and inundation of a number of coastal regions. This problem, raised by Mercer (1979), requires special study.

Water regime of the continents. The matter of a change in the precipitation regime is of great importance. Without question, an increase in the mass of $CO_2$ will lead to an increase in evaporation from the surface of the oceans, and accordingly, an increase in the quantity of precipitation falling on the earth's surface. Menabe and Wetherald, in computations using the general theory of climate, found that a doubling of the mass of $CO_2$ increases the total quantity of evaporation and precipitation by 7% (Manabe, Wetherald, 1975). However, from this investigation it is impossible to obtain information on the change in distribution of precipitation over the continents during warming.

It was established in empirical investigations that warmings exert a considerable influence on the distribution of precipitation. Over the greater part of the surface of the continents in the temperate latitudes the quantity of precipitation decreases (Drozdov, Grigor'yeva, 1963; Budyko, Vinnikov, 1973; Lamb, 1974, and others).

The reason for such a change in the precipitation regime is clear: since during a warming the temperature in the high latitudes increases more than in the low latitudes, a decrease in the temperature difference between the equator and the pole reduces the intensity of atmospheric circulation and reduces the quantity of water vapor transported from the ocean onto the continents. Thus, a warming leads to an increase in the precipitation falling primarily on the surface of the oceans. At the same time, during a warming there is a decrease in the quantity of precipitation over a considerable part of the surface of the continents; this can be of importance for many natural processes and for the economic activity of man.

It was established that during a warming there is some change in the latitudinal distribution of precipitation. In particular, it follows from the data published by Lamb that in the time interval 1931-1960, in comparison with the period 1960-1969, the mean latitudinal quantity of precipitation decreased at all latitudes to the north of 30°N, in the zone from 10 to 30° N the precipitation sum was increased, whereas in the equatorial zone it again decreased (Lamb, 1974). We note, as can be seen from the Lamb precipitation maps, that his data pertain for the most part to the continents.

Other materials are available from whose analysis it follows that there is a possibility of a decrease in the quantity of precipitation in a number of continental regions when there are relatively small changes in climate in the direction of a warming. Evidently, the precipitation regime is particularly sensitive to variations in the thermal regime in zones of unstable moistening (steppes and wooded steppes) of the middle latitudes in Europe, Asia and North America. Since these zones are of greater importance for agriculture, a change in the precipitation regime in them can exert a considerable influence on the global balance of food production.

Without question, due to the annual variations in precipitation the trend in the change in their sums caused by the development of warming can be discovered with the use of considerable averaging in space and time. In the epoch of warming, in individual regions of the zone covered by a tendency to a decrease in precipitation there is a variation in the sums of precipitation in the direction of both a decrease and an increase, although the frequency and mean amplitude of anomalies of different sign are different. Accordingly, during warmings there is an increase in the frequency of occurrence of major droughts occupying great territories. Such an effect was established both for the warming of the 1930's and for the period 1972-1976, when droughts of rare intensity were observed annually in Europe, Asia and North America.

It is possible that the frequency of recurrence of droughts increases particularly sharply at the onset of the development of the warming process, which is usually manifested somewhat earlier in the high latitudes in comparison with the low latitudes. Such a pattern leads to an additional decrease in the meridional temperature gradient, and accordingly, to a weakening of the moisture cycle in the atmosphere.

In studying the changes in the moisture cycle which will occur before the melting of sea polar ice, it is also possible to use empirical estimates based on data on variations of precipitation in the recent past. However, it is clear that it is difficult to use such an approach in an investigation of the moistening conditions in an ice-free period, the climate of which is sharply different from the meteorological regime of our times.

In an earlier study (Budyko, et al., 1978) data on the climate of the Neogene were used for this purpose. It was clarified in this investigation that with a doubling of the concentration of carbon dioxide in comparison with the preindustrial epoch the quantity of precipitation over the greater part of the territory of Europe and the extratropical regions of Asia increases, particularly in the high latitudes.

These data on precipitation were used in computing the quantities of river runoff in the indicated territory for the conditions of a doubled concentration of carbon dioxide. Taking into account data on the change in evaporability (which increases in the entire considered territory as a result of an increase in the radiation balance of the earth's surface and an increase in air temperature) it was possible to construct a map of river runoff whose quantity over the greater part of the territory was appreciably greater than its present-day values.

Geographic zonality. The dependence of geographic zones on climatic factors was studied in the works of A. A. Grigor'yev and the author (Grigor'yev, Budyko, 1956, 1959), in which a periodic table of geographic zonality was constructed. In accordance with this table, under conditions of adequate moistening the position of the geographic zones for the most part is determined by thermal and energy factors. Taking into account the dependence of the position of the geographic zones on the air temperature sums during the growing season established for this case, it can be computed how this situation changes during climatic variations. The results of such computations are presented in Figure 4 (left side of graph — change in the mean latitudinal boundaries of the geographic zones in the northern hemisphere in the Neogene, right part of graph -- same for the 20th and 21st centuries). It can be seen that at the end of the Tertiary the geographic zones situated under the conditions of a moist climate first slowly and then more and more rapidly moved southward.

This conclusion is confirmed by paleogeographic data, from which it follows that the natural conditions of the Neogene differed sharply from the natural conditions of the present-day epoch. In the Miocene in the central regions of Western Europe there was widespread occurrence of forests, including evergreen plants, this including palms. In the northern part of Europe, to Spitzbergen, there were coniferous-hardwood forests of a rich composition, consisting of birches, beeches, oaks, pines, firs and other trees. In southeastern Europe, where there is now a steppe zone, first there were beech-oak forests, also including some evergreens, which were then replaced by savannahs. The northern part of Asia was occupied by fir-hardwood forests.

During the Pliocene the principal geobotanical zones were shifted southward, although at this time they were situated in higher latitudes in comparison with the present-day epoch (Sinitsyn, 1965).

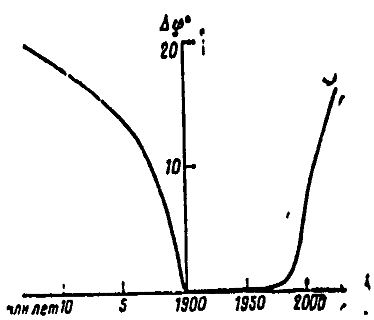

Fig. 4. Change in position of geographic zones. Along-x-axis: millions of years

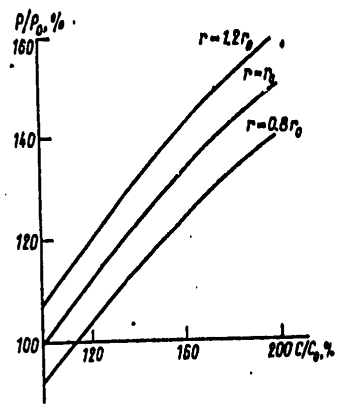

Fig. 5. Dependence of productivity of autotrophic plants on the concentration of carbon dioxide and quantity of precipitation.

The data at the right side of the graph show that toward the end of the first quarter of the 21st century there should be a movement of the geographic zones into the higher latitudes for a distance attaining 15°.

A study of data on climate of the future makes it possible to conclude that the geographic zones in regions of inadequate moistening change their position far less because the increase in evaporability caused by the warming will in most cases be compensated by an increase in the quantity of precipitation. However, even under this condition the geographic zones in the 21st century will differ sharply from the geographic zonality of recent centuries. It must be surmised that during a short period of several decades there could only be a partial adaptation of different components of the physiographic process to the new climatic conditions. At the same time, one must not underevaluate the plasticity of many of these components, which frequently react rapidly to climatic changes. For example, in particular, A. A. Grigor'yev (1946) pointed out that during the time of the relatively brief warming of the 1920's-1930's the northern boundary of the forest in a number of regions of the wooded tundra was considerably displaced into the higher latitudes. It is obvious that the problem of change in geographic zones under conditions of such a rapidly transpiring evolution of the biosphere requires special investigation.

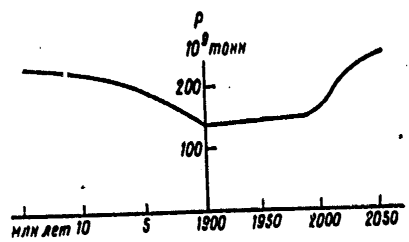


Fig. 6. Change in productivity of natural vegetation cover. Along x-axis: millions of years; along y-axis: tons

Productivity of the vegetation cover. As noted above, the problem of the productivity of the vegetation cover is of great importance for evaluating the energy resources supporting almost the entire mass of organic matter of living organisms in the biosphere.

Laboratory experiments and field investigations show that when there is adequate moistening and other favorable conditions the productivity of autotrophic plants is directly proportional to the concentration of carbon dioxide in the air in the range of values of this concentration from its present-day value to values several times greater. A quantitative estimate of the influence of the concentration of $CO_2$ on productivity can be obtained by using numerical models of photosynthesis in the layer of the vegetation cover, which during recent years are being developed by many researchers.

Figure 5 represents the dependence of the productivity of wheat on the concentration of carbon dioxide and the quantity of precipitation, calculated using the G. V. Menzhulin model (1976) for the mean climatic conditions for the cultivation of wheat in the territory of the USSR. It can be seen from this graph that the productivity increases proportionally both with respect to the concentration of carbon dioxide and to the quantity of falling precipitation. An increase in the concentration of $CO_2$ or precipitation by 10% in both cases leads to an increase in productivity by 4-5%.

Taking into account that a similar dependence should also be observed for the natural vegetation cover under conditions of adequate moistening, it can be postulated that with changes in the concentration of atmospheric carbon dioxide there are corresponding changes in the total productivity of autotrophic plants. These changes are intensified due to changes in the thermal regime of the earth's surface associated with variations in the mass of $CO_2$.

Although an increase in the temperature of plants, all other conditions being equal, frequently leads to a decrease in productivity as a result of an increase in the expenditure of organic matter in respiration, a global warming favors an increase in the total productivity of plants on the continents due to a broadening of the expanses occupied by more productive vegetation covers.

It can be surmised that the total productivity of vegetation when there is an increase in the $CO_2$ concentration in the atmosphere should increase due to the direct influence of the change in the concentration of carbon dioxide, an increase in the precipitation sums over the greater part of the continents and an increase in the area of the most productive zones due to their extension into the higher latitudes. Allowance for the influence of all these factors on productivity involves great difficulties. Some results of an approximate evaluation of this dependence, given by N. A. Yefremova, are presented in Fig. 6. The left side of this graph shows the change in total productivity of the vegetation cover on the continents at the end of the Neogene. The right side of the graph characterizes the possible change in productivity in the future during the development of global warming. It is extremely possible that the conclusion which can be drawn from this graph that there is an increase in total productivity after several decades by approximately 50% in actuality would not hold true, since during such a short time the natural vegetation cover does not attain the state of a climax corresponding to the rapidly changing environmental conditions. However, it must be expected that with an increase in the concentration of carbon dioxide the mean productivity of both natural vegetation covers and agricultural fields will increase appreciably.

Summary. The following conclusions can be drawn from the presently available data.

1. The economic activity of man, associated with the combustion of an ever-increasing quantity of fossil fuel, is changing the chemical composition of the atmosphere. This change is rapidly intensifying. The increase in the quantity of atmospheric carbon dioxide has already led to an increase in mean air temperature at the earth's surface by several tenths of a degree, and in the future, if the present-day trends in the development of power persist, it is possible that already after several decades the mean air temperature will increase by 2-3°. This can lead to the destruction of sea polar ice, which would additionally intensify the changes in climatic conditions in the high and middle latitudes of the northern hemisphere.

2. Computations made using models of the theory of climate and paleoclimatic data make it possible to construct forecasting maps of climatic conditions of the future. Using these maps it is possible to note what changes

can be expected in different components of the environment as a result of an increase in the quantity of carbon dioxide in the atmosphere. It is possible to predict the probability of changes in natural conditions over the entire earth, especially in the middle and high latitudes.

3. In order to comprehend the changes now transpiring in the state of the biosphere it is important that an increase in the quantity of carbon dioxide returns the atmosphere to a state typical for the Tertiary period with far warmer climatic conditions and a higher productivity of the vegetation cover in comparison with the present-day epoch.

In examining the process of impoverishment of the atmosphere with carbon dioxide, which predominated over the course of the last hundred million years, as a direct threat for existence of the biosphere, in connection with a decrease in the productivity of autotrophic plants and the possibility of a total glaciation of the earth, it must be assumed that the present-day anthropogenic effect on the biosphere is favoring an elimination of this threat.

4. Many aspects of the global warming process can be favorable for mankind (increase in the productivity of autotrophic plants, broadening of the possibilities of economic use of areas with a cold climate, etc.). However, it is necessary to take into account the inevitability of a number of difficulties which arise in connection with this process. The most important of these is the need, in a relatively short period of time, to adapt many branches of economic activity to the conditions of a rapidly changing climate and other environmental components.

5. Since a prediction of global changes in climate and their principal consequences is extremely complex, it is desirable to organize their study so as to be ready to take these consequences into account in the planning of economic activity. In particular, in addition to the problems enumerated in this article it is necessary to study how during the development of a warming there will be destruction of permafrost in the upper soil layers. A question worthy of attention is the fate, under warming conditions, of the intracontinental glaciers, of which many are of great importance for the water regime of arid regions. It is important to investigate the influence of climatic changes on the soil-forming process. One of the most acute problems which arises with a rapid change in climate will be the problem of preservation of many species of wild animals and plants: their existence will be threatened as a result of destruction of the corresponding ecological systems. This also applies to the prospects for the preservation of supplies of commercial fish, many of which are highly sensitive to changes in climatic conditions.

The number of such problems is very great because the change in global climate exerts an influence on many of the components of man's environment.

6. In connection with the above, there must be a maximum acceleration of the organization of broad interdisciplinary investigation of the anthropogenic process of global warming and its influence on the environment. Specialists of the institutes of the USSR Academy of Sciences, the Academies of Sciences of the union republics, the Committee on Hydrometeorology and Environmental Monitoring and other departments should participate in this investigation.

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[451]

II. TERRESTRIAL GEOPHYSICS

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Translations

## CONTRASTIVITY OF TECTONIC MOVEMENTS AND THEIR SIGNIFICANCE AS A GEOLOGICAL INDICATOR OF SEISMICITY

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[Article by P. N. Nikolayev]

[Text] Determination of the contrastivity of movements is of considerable importance in categorizing the geostructural elements of the earth's crust, establishing the pattern of tectonic movements and identifying general tectogenetic patterns [3, 9, 23 and others]. In addition, this concept is of considerable practical importance, e.g. in seismotectonics for the analysis of the seismic danger in an area, in engineering-geological research, for forecasting slides and the like. Accordingly a number of investigators have attempted to make use of quantitavive indicators of contrastivity.

The term "contrastivity" is generally used to mean a difference in the intensity of tectonic movements in neighboring sectors or blocks of the earth's crust [24], manifested primarily as changes in the overall amplitude of dislocations or as differences in average rates of movement. We are aware of attempts at quantitative analysis of contrastivity involving the making of charts of average gradients of vertical tectonic movement [3, 4, 19 and others] followed by determination of their scope [11] or weighted average values [7], and also the use of various statistical indices such as the standard deviation [2] or variance [10] of the amplitudes of tectonic movements. The latter index and certain modifications of it have been studied in especial detail by V. N. Sholpo [24, 25].

The inadequacy of the statistical indicators in current use is shown by the fact that when used to characterize a given region as a whole they do not give a smooth map of the contrastivity of tectonic movements over the area, which makes it difficult to use them for practical purposes. In addition, since the standard deviation and variance are absolute indicators of the variability of these amplitudes, they can be used for comparative analysis only in analogous areas in which no large difference in the average amplitudes of tectonic movements is observed. In fact, if the standard deviation is 100 m in an orogenic region with an average amplitude on the order of several thousand meters, this indicator will indicate that the area is quite homogeneous, monolithic, and with a small contrastivity of movement; but for a platform area with typical average amplitudes of a few hundred meters, the same standard deviation would indicate differentiation within the area. The gradient, which is also an absolute index with all the attendant shortcomings, indicates the maximum rate of change of movement amplitude (and the corresponding average speed) at each point on the map, which makes it difficult to conduct a comparative analysis of the significance of various areas. Indeed, since it is highly sensitive to the curvature of "tectonic relief," the gradient varies from zero (for closed contours) to infinity (in regions of abrupt dislocation) in practically any geostructural region. The considerable variation in gradient values results, according to our analysis, in differences in its average values for different regions, even when a coarse scale is used on the map, and it is frequently statistically unreliable.

However, the basic methodological difficulties in quantitative determination of contrastivity spring from the nature of tectonic movements themselves and from the lack of a genetic classification of them. The problem is, as has frequently been noted in the literature (e.g. references 9, 23 and many others), that tectonic movements are governed by an immense number of complexly interacting factors of diverse origin, occurring at different depths, acting for different lengths of time and having different "spheres of influence". The tectonic movement amplitude which is entered on the map in the form of isometric lines is the result of simultaneous action of planetary and celestial sources of motion, of sources which determine the tectonic motion of a given structural area as a whole and of purely local sources in the crust. In addition, depending on purely local conditions and the physical and mechanical properties of the medium, the action of a given source can produce differing results, i.e. different amplitudes of tectonic movement, in different places. It is important to note in this connection that different "sets" of sources may operate in different geostructural regions. This leads to major methodological difficulties in the interpretation of comparative analytical results, since it entails comparison of the overall effects of complexes of factors which differ in both number and character. This considerable indeterminacy is an especially important consideration when selecting a mathematical model for quantitative analysis of tectonic movements.

The complexity of the subject of study renders mathematical methods effective only in the solution of partial or second-order problems. In solving the most complex problems, however, and particularly in characterizing the contrastivity of tectonic movements, it is necessary to introduce such rigid conditions and limitations on the physical character of the phenomena, as regards either the properties of the medium undergoing deformation or the nature and spatial distribution of the sources of movement, that the models that are produced are excessively schematic and specialized and are remote from reality [12, 21 and others]. The mathematical analysis of complex natural phenomena has the most promise not where the subject is presented as a simple and rigidly determined model, but where a preliminary analysis of its structure is made, allowing the identification of a number of independent and functionally integral elements and the identification and analysis of the way in which they interact so as ultimately to govern the phenomenon being studied.

Current experience in various fields of science indicates that "presenting the object of study as a system and dividing it up for detailed structural analysis is an intermediate step which simplifies mathematical modeling of its function" [21]. Thus, "the systems approach is one of the preconditions and methods of mathematization of modern science" (idem), and is in particular a precondition and a method of quantitative analysis of tectonic movements.

The use of the systems approach to the analysis of tectonic deformations and resultant tectonic movements and stress fields has made it possible to determine within each geostructural region a hierarchy of geodynamic systems of various ranks, the interaction among which determines the geodynamic system of the region in question [14]. By "tectodynamic system" we mean the totality of the interacting conditions and factors which govern the mechanism of deformation and the stress state of a region of the earth's crust which is homogeneous at a given structural level, and the associated tectonic movements. The largest tectodynamic systems, of the lowest ranks, govern tectonic movements associated with planetary and celestial sources and have long times of action and great spatial consistency. Tectonic movements corresponding to higher-rank tectodynamic systems depend on local factors and typically are spatially nonuniform. Tectodynamic systems of various orders are responsible for the formation of structures on differing scales (different structural levels), but this relationship is clearly complex and structures of various orders may be referred to a single rank.

Thus the identification of the tectodynamic system of a given rank entails analysis of the interaction of the totality of factors giving rise to a new integral quality which manifests itself primarily in the integrality and functional uniformity of the object of study, e.g. in the new integral properties of a structure that is homogeneous (at the structural level in question) or a new mechanism of deformation characterized by its tectonic stress field and governed by the type of tectonic structure. The amplitude chart shows the overall resultant effect of individual tectodynamic systems belonging to different hierarchical levels and characterized, as also shown in references 1 and 15, by their mechanism of tectonic deformation and the kinematics of tectonic movement. Moreover, as already indicated, since we know beforehand neither the number of tectodynamic systems affecting a given area and manifesting themselves on a map of a given scale nor the spatial distribution of the systems of higher rank, we cannot say what our indices of contrastivity relate to, what they characterize, which of them can be considered typical of a given geostructural region as a whole, and which of them result from the superposition of higher-rank tectodynamic systems. Clearly tectonic movements associated with the operation of tectodynamic systems of each rank can be characterized by their set of kinematic indices (including the contrastivity of movements of the rank in question).

An extremely pressing current problem is that of differentiating the kinematic characteristics of tectonic movements caused by tectodynamic systems of various ranks and making the corresponding rank maps. The solution of this problem is of great theoretical importance (for comparative analysis and classification of tectonic zones, development of genetic classifications of tectonic movements and so on) and also of practical significance, especially for the prediction of strong earthquakes, since the prognostic signs must correspond to the rank of the phenomenon being forecast.

This paper described our experience im making rank maps for contrastivity of recent tectonic movements in the Caucasus. Our earlier analyses indicated that in this territory (on a scale of 1 : 2,500,000) three major recent tectodynamic systems of different rank could be distinguished, differing by deformation mechanism and corresponding tectonic stress fields [15]. As was noted by M. V. Gzovskiy [3 and elsewhere], the tectonic discontinuities formed in a given field, which show a regular orientation relative to the axes of the main normal stresses and thus form two conjugate systems, can be used as an indicator of the stress field and accordingly of the deformation mechanism of any area of the earth's crust. Accordingly, the orientation of the conjugate discontinuities, which differs for different tectodynamic systems [15], can be used as the determining characteristic of each tectodynamic system. Another important characteristic is its homogeneity and integrality, which will show up primarily in a uniform pattern of orientation of discontinuities [razryvy] within the region subject to the operation of the tectodynamic system in question.

As indicated above, the size of the "sphere of influence" depends on the rank of the tectodynamic system, and accordingly we may expect that investigations carried out on various scales and at different levels of generalization will describe different combinations of tectodynamic systems at various hierarchical levels. This is confirmed by the results of work by V. D. Skaryatin, who showed for the Northern Caucasus that changing the level of generalization changes the predominating orientation of abrupt dislocations [20], and that "each scale...has its own specific geological information" (ibid). To identify a particular tectodynamic system, the selected level of generalization must most of all assure the homogeneity and integrality of the subject of generalization; this is indicated by uniform orientation and spatial distribution of abrupt dislocations, forming the proper network, or simplicity of the structures on the map, not complicated by additional deformations of sharply differing higher orders. We used such an approach and we have described in detail its use to identify structurally homogeneous sectors so as to reconstruct the tectonic stress fields in the area of construction of the Inguri GES (West Caucasus) [16].

Any quantitative indicator of the contrastivity of tectonic movements may be used as an indicator of faults.

The numberous works of M. V. Gzovskiy, D. N. Osokina, A. S. Girgor'yev and many other writers show that high gradients of the rate of vertical tectonic movement can be considered as unambiguous indicators of the presence of a subterranean fault. However, it is not expedient to use the gradient to make rank maps of the contrastivity of tectonic movements, owing the characteristics of this indicator which were mentioned above and have been discussed previously in a special article [12].

As contrastivity indices we used the coefficient of variation cv, widely used in statistics and biometry, which is calculated by the following formula [17, 22 and elsewhere]: $cv = 100\sigma/M\%$, where $\sigma$ is the standard deviation and M is the average value of the quantity being analyzed.

The coefficient of variation of the amplitudes of recent tectonic movements is calculated for a certain averaging area corresponding to the selected level of generalization. By showing the amount of amplitude deviation from the average value for the averaging area in question as a percentage of the average amplitude, the coefficient of variation is similar in the physical sense to the gradient, and sharp increases in its value can be considered as an indication of faults. However, as a dimensionless relative indicator, the cv lacks the shortcomings of the gradient which are described above and can be used to varying degrees for characterization and comparative analysis of widely divergent geostructural regions. In addition, the calculation procedure for this index makes it extremely convenient for subsequent generalization of the movement characteristics of various tectodynamic systems. Calculating coefficients of variation by the formula given above is unusually laborious even when an averaging grid of large area is used. Test constructions indicate that for our purposes it is quite adequate to derive approximate values for $\sigma$ and M using the simplified formulas [17]: $\sigma = h_{max} - h_{min}/K$; $M = h_{max} + h_{min}/2$, where $h_{min}$ and $h_{max}$ are the minimum and maximum values of the amplitude of movement within the averaging area, and K is a coefficient can be determined from special tables [6]. Our analysis shows that the best results for maps on a scale of 1 : 2,500,000 are obtained for $K = 5$. Clearly the simplification could be dispensed with if good calculating equipment were used.

To select an averaging area with a size corresponding to the rank of the tectodynamic system being analyzed, we proceeded as follows. As in icated earlier, seismic data from the Caucasus which are currently available show that the maximum linear extent of structural nonuniformities which can correspond to different tectodynamic systems is about 20-40 and 80-100 km. The map of recent tectonics in the Caucasus [8] shows that within this area it is possible to identify major structural nonuniformities and major structural elements (arch uplifts and downwarps) with cross-sectional dimensions of 100-150 km and longitudinal dimensions of 100-1000 km with a typical size of 300 km. These structural elements differ not only in the history of their geological development and the direction of recent and current tectonic movements and structure, but also in the thickness and structure of the earth's crust and the nature of the gravitational field, and thus they show major nonuniformities of the lithosphere. As shown by Ye. V. Artyushkov, these nonuniformities of the lithosphere produce anomalities in stress states. Thus, we have blocks which are clearly demarcated areally and have nonuniform stress states and characteristics of recent movements and deformations. Clearly these determine one of the lowest (and largest) ranks in the hierarchy of tectonic systems.

In addition, analysis of existing geological materials enables us to establish the block structure and subdivisions of the crust in the Caucasus at both coarser and finer structural levels. To analyze the block structure of recent deformations in the Caucasus, we made a chart of horizontal interactions (using a method described previously [13]) which showed the axes of zones with a rotary tectonic movement rate field, thus indicating the outlines of the individual blocks with their characteristic tectonic movement rate potential fields [13]. Using this formalized method, we identified 1,339 blocks of different sizes and shapes. In addition we determined the areas of the blocks and organized the blocks, with their potential fields for rates of recent tectonic movement, in series by area, ranging from 6 to 3,700 $km^2$.

Fig. 1 shows the distribution of the areas of recent blocks in the Caucasus. This graph was produced using an algorithm for separating useful signal from background noise and establishing a hierarchy of signals [5], which enabled us to divide it into four sections corresponding to four groups of blocks of various sizes (Fig. 1). The first group includes blocks with areas of 400 $km^2$ or less, the second those with areas from 400 to 800 $km^2$, the third those with areas from 800 to 1,300 $km^2$ and the fourth those with areas greater than 1,300 $km^2$ (with an average of about 2,500 $km^2$). It is important that the average sizes of the blocks in the second and third groups correspond to the sizes typical of average distances between the epicenters of earthquakes in the 9th and 11th energy classes [15], indicating a connection between earthquakes of different strengths and deformations at different structural levels belonging to different tectodynamic systems. The analysis of the above material enables us to hypothesize that the three largest tectodynamic systems reconstructed for the Cuacasus [15] are characterized by linear nonuniformity sizes of 200-300, 80-100 and about 50 km. In addition, we clearly may expect to find tectodynamic systems of higher ranks with characteristic linear dimensions of about 35 and 25 km.

In our rank analysis of the contrastivity of recent tectonic movements we naturally use averaging areas corresponding to the sizes of crustal nonuniformities of various ranks. We tested three areas: 50 x 50, 100 x 100 and 200 x 200 km. Determination of the average amplitude of recent movements and the standard deviation were made for 50 x 50 km subdivisions using the simplified formulas given above. In drawing up the map of coefficients of variation of the amplitudes of recent tectonic movements, we used the well-known "sliding window" method: to calculate each new value to be assigned to the center of a subdivision [paletka], the previous subdivision was shifted vertically and horizontally by half its area. The biometric literature [22] generally does not recommend calculation of the coefficient of variation in cases where the quantity being studied can have both positive and negative values. But it seemed to us that the nature of the geological subject and the generally observed high contrast of tectonic movements at the edges of downwarps and uplifts could be successfully accentuated by a sharp increase in the value of the coefficient of variation of the amplitudes of movements on averaging areas which included adjoining sectors that experienced shifts in the same directions. Accordingly the calculation of coefficients of variation was made not for the individual geostructural elements of the Caucasus but for the entire area in question, using the absolute value of the average movement amplitude as the denominator. Thus the calculated values of the coefficient of variation were distributed over a square grid with a spacing of 25 km, corresponding to 1 cm on a map with a scale of 1 : 2,500,000.

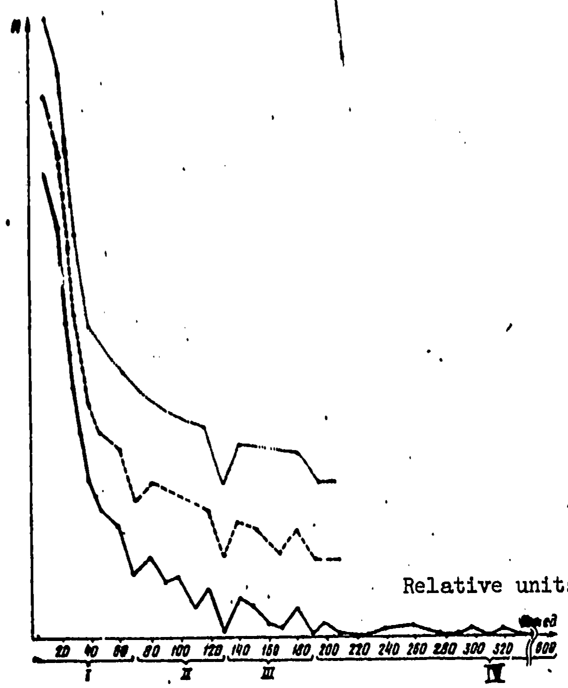


Fig. 1. Distribution of Block Structure of Recent Tectonic Movements in the Caucasus (Explanation in Text).

Using the resulting data, we drew a map of areal variations of the coefficient of variation in the form of contour lines (Fig. 2). A comparison of this map with a map of gradients of the rate of vertical tectonic movements in the Caucasus drawn up by Ye. Ye. Milanovskiy [8] indicated that the zones of high coefficient of variation of the amplitude of recent movements (100% or greater) corresponded entirely to the zones of high gradient. In addition, the zones of contrastive tectonic movements in the Cis-Caucasian area on the chart of coefficients of variation were much more clearly demarcated and gave a better indication of the block structure of the crust, while the effect on evaluation of the contrastivity of absolute values of the amplitudes was less pronounced. In view of the fact that the labor required to draw up a chart of cv's is considerably less than that for a chart of gradients, such charts can be recommended for practical use. Analysis of the map (Fig. 2) showed that the entire territory considered manifested an insignificant variability of amplitude of recent tectonic movements with respect to average values in areas measuring 2,500 km$^2$. The coefficient of variation of amplitudes practically nowhere exceeded 30%, indicating a highly uniform distribution of amplitudes over the averaging areas. Moreover, we observed narrow zones of much higher coeffieicnts of variation, which outlined, as it were, monolithic crustal blocks. Analysis of the trends of the axes of maximum cv indicates

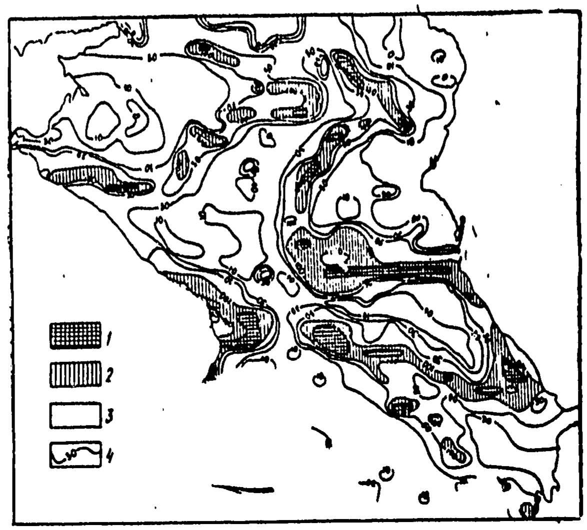


Fig. 2. Contrastivity of Recent Tectonic Movements in the Caucasus: Third-Rank Tectodynamic System

Values of coefficient of variation of movements on averaging areas of 2500 $km^2$: 1--150% or greater; 2--100-150%; 3--less than 100%; 4--isometric lines.

that the majority of them are directed in a sublatitudinal or north-west (Caucasian) direction. Of secondary significance are submeridional and north-east trends. Accordingly, the trends of the axes of maxima correspond to the fault trends noted by many observers in the Caucasus.

It is interesting that within the major junction [shovnyy] zones of the Caucasus, the maxima of the coefficients of variation at a given level of generalization had trends which indicated certain elements of the internal structure of these zones. The Kakhetino-Lechkhumska junction zone, for example, shows downwarping in a number of sectors, with sublatitudinal direction, connected by sectors with the general north-west oriantation of the Caucasus.

Since earthquakes in various energy classes are evidently connected [14, 15] with the operation of various tectodynamic systems, and since the level of generalization selected for the construction of Fig. 2 corresponds to nonuniformities identified by seismic data, it is necessary to determine the relationship between seismicity and the distribution of coefficients of variation of the amplitudes of recent tectonic movements over the Caucasus area. For this purpose, following reference 15 we identified a group of weak earthquakes in the Caucasus with epicenters of K= 9 and 10 which were connected with a tectodynamic system of a higher "seismogenic" rank, and also a group of strong earthquakes with K = 11, 12 and 13, connected with a seismogenic tectodynamic system of lower rank. For each of these groups of epicenters we drew up a map of densities using the requisite averaging areas. Next we performed a variance analysis of the distribution of zones with different densities of strong and weak earthquakes as a function of the distribution of values of the coefficient of variation of the amplitude of recent tectonic movements in the Caucasus in areas of 2,500 km$^2$ (i.e. as a function of the contrastivity of neotectonic movements corresponding to the third-rank tectodynamic system). The results of the analysis are presented in the table.

We can see that the contrastivity of recent movements at the selected high level of generalization is closely connected with the distribution of densities of epicenters of powerful earthquakes in the Caucasus. Corrected for the totality of these, the size of the correlation is approximately 18%, an extremely high figure. The connection of contrastivity with distribution of weak earthquakes is still significant, but somewhat less so, and the effect of the contrastivity factor does not exceed 6.33% in the totality of factors governing the areal distribution of weak earthquakes in the Caucasus. The effect of this factor thus decreases to about 2%.

Variance Analysis of the Connection Between Seismicity and Contrastivity of Recent Third-Rank Movements

| Землетрясения 1 | Количество точек наблюдения 2 | Процент влияния контрастности 3 | Доверительные границы генерального показателя, уровень значимости 0,95 4 | Расчетные значения F 5 | Табличные значения F для трех уровней значимости 6 |
|---|---|---|---|---|---|
| Слабые 7 | 930 | 3,9 | 1,6— 6,33 | 6,3 | 3,8—3,0—2,1 |
| Сильные 8 | 925 | 15,87 | 13,8—17,96 | 28,88 | 3,8—3,0—2,1 |

Key:
1. Earthquake
2. Number of observation points
3. Percent effect of contrastivity
4. Confidence range of general index, 95% significance level
5. Calculated value of F
6. Values of F from table for 3 confidence levels
7. Weak
8. Strong

Thus the low degree of connection between contrastivity indices for recent movements (in particular the rate gradient) and seismicity which has been noted by a number of investigators may be explained by the different ranks of the phenomenon being forecast (seismicity) and the prognostic characteristic (the gradient). We may state that the informativeness of a geological criterion increases sharply if a differentiated analysis of phenomena of the same rank associated with the operation of a single tectodynamic system is carried out in advance. Indirect confirmation of the foregoing is the connection between contrastivity (Fig. 2) and a map of the detail [drobnost'] of recent movements [13]. A variance analysis conducted by us shows that if the detail has a significant effect on the distribution of zones of high contrastivity of recent movements, the contribution of this factor to the totality does not exceed 22%. Accordingly, 78% of the faults observed in the Caucasus, including those capable of producing earthquakes, are connected with the e..ects of tectodynamic systems of other ranks.

To calculate the contrastivity of recent movements of the next (lower) rank we used the figures obtained in making the map of Fig. 2. This significantly increased the accuracy of our constructions compared with the above-mentioned simplified method. The calculation of a "standard" was made using the formula for standard deviation of the sum of independent random variables, thus showing the "accumulated deviation" for all the base areas:

$$\sigma(h) = \sqrt{\sigma^2(h_1) + \sigma^2(h_2) + \ldots + \sigma^2(h_n)};$$

the mean was calculated as the arithmetic mean of the figures previously obtained. Averaging was done on 100 x 100 km areas corresponding to 25 previously calculated values. The results were referred to the area centers and a new grid of values for cv with a spacing of 50 km was obtained [2]. The generalization of these data using isometric lines for the values of the coefficient of variation of amplitudes of tectonic shifts in averaging areas of 10,000 $km^2$ is shown in Fig. 3. At this level of generalization the territory divides into two unequal areas. In the north, in the Cis-Caucasian region, the isometric lines for the coefficient of variation have a north-west and north-east orientation. In the Caucasus the orientation of the cv maxima has a clearly marked sublatitudinal and north-west tendency. According to data in reference 15, the formation of sublatitudinal upthrusts with a small leftward slip component, and rightward strike-slip faults oriented in a north-west direction is typical of the second-rank tectodynamic system in the Caucasus. The consistency of the structural pattern, shown in Fig. 3, and the complete correspondence of the trends of the axes of maximum coeffients of amplitude variation with the trends of the major faults formed in the second-rank tectodynamic system convince us that the diagram in Fig. 3 matches the contrastivity of recent tectonic movements connected with the operation of the second-rank tectodynamic system. The same applies to the Cis-Caucasian area; the isometric line patterns for the coefficient of variation in this area will be described below.

A chart of the contrastivity of second-rank tectonic movements (Fig. 4) was drawn up using averaging areas of 200 x 200 km laid out as above. The orientation of isometric lines for the coefficients of variation of amplitudes of recent tectonic movements at this level of generalization had a clear north-west and north-east trend throughout the territory. A comparison of the trends of the cv's with the trends of the faults formed in the first-rank tectodynamic system [15] showed that the north-west orientation coincides closely with the trends of the rightward strike-slip normal faults, and the north-east tendency with the leftward faults with a minimal normal component. The uniformity of the structural diagram of the territory and the correspondence of the trends of high coefficients of variation with the large faults of the corresponding rank convince us that the diagram presented in Fig. 4 corresponds to the contrastivity of tectonic movements associated with the first-rank tectodynamic system.

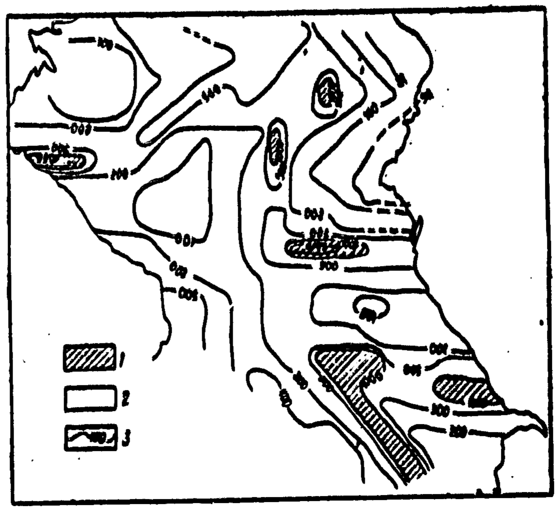

Fig. 3. Contrastivity of Recent Tectonic Movements in the Caucasus: Second-Rank Tectodynamic System.

Value of the coefficient of variation of amplitudes of movements on 10,000-km$^2$ averaging area: 1--over 1000%; 2--less than 1000%; 3--isometric lines.

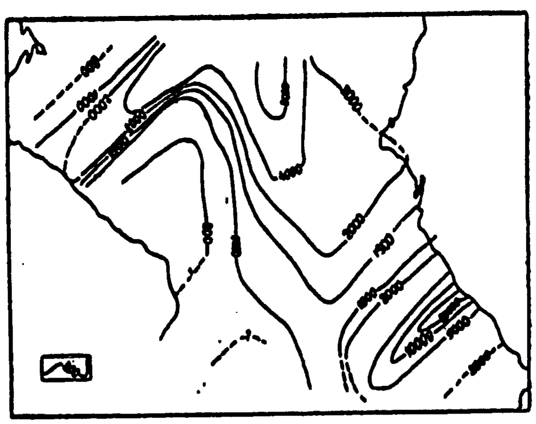

Fig. 4. Contrastivity of Recent Tectonic Movements in the Caucasus: First-Order Tectodynamic System.

The isometric lines indicate equivalence of the coefficient of amplitude variation on an averaging area of 40,000 km$^2$.

The connection between the distribution of values of the coefficient of amplitude variation with fault zones, mentioned above, enabled us to draw up a diagram of the main faults of various ranks governing the contrastivity of recent tectonic movements in the Caucasus and Cis-Caucasia (Fig. 5.). Analysis of this diagram indicates that the recent tectonics of this territory is governed primarily by a system of slip dislocations trending north-west and north-east, which corresponds in general terms with the conclusions of G. D. Azhgirey and L. M. Rastsvetayev [18]. Particularly important is the fact that the zones of these dislocations show a contrast with recent movements in the orogenic area only in the first-rank tectodynamic system, while on the platform they are already fixed in the second-rank tectodynamic system (Fig. 5). Since the first-rank system is more regional and includes both orogenic and platform territories, the second-rank tectodynamic system is specific to the orogenic area, i.e. the complex of factors associated with this system is localized within the orogenic area (orogenic proper). It governs the kinematics of properly orogenic tectonic movements, which appear in the formation of sub-latitudinal and north-west zones of higher contrastivity and of the corresponding systems of overthrust [nadvigovyy] and reverse thrust [vzbrosovyy] fault dislocations (fig. 5). The third-rank tectonic movements (corresponding to the third-rank tectodynamic system) are located in both orogenic and platform areas. They form a complex system of fault dislocations corresponding to zones of high contrastivity and are typified by the formation of a diagonal system of faults which clearly have an important slip component, by latitudinal faults, apparently of a reverse-thrust character, and submeridional faults which are apparently of a normal character (Fig. 5).

The complexity of the diagram of fault dislocations connected with the operation of third-rank tectodynamic systems and previous analysis of the tectonic stress fields of the Caucasus [15] enable us to assert that this system depends on a heterogeneous tectonic stress field in which relatively small structures are formed in the upper part of the crust.

The structures of this rank may be encountered in both platforms and orogenic regions; they have been formed as a result of both vertical and horizontal forces. A system of such Holocene-late Pleistocene dislocations, apparently belonging to a tectonic system of this rank, was described by V. G. Trifonov for the Eastern Caucasus [26].

Thus, the recent tectonics of this territory is the result of a complex interaction of tectodynamic systems of various ranks. Our proposed method enables us the perform a differentiated analysis of the kinematics of recent movements in each of these ranks. We are able to distinguish a group of movements associated with a properly orogenic complex of factors, a regional component typical of both orogenic and platform areas, and a local component associated with a complex of factors that lead to the formation of local structural forms. It may be hoped that this method of ranked analysis of the kinematics of tectonic movements can serve as the basis for a generic classification of them. In addition, the use of this method will make possible a sharp increase in the informativeness of geological forecasting signs, in particular for the forecasting of strong earthquakes.

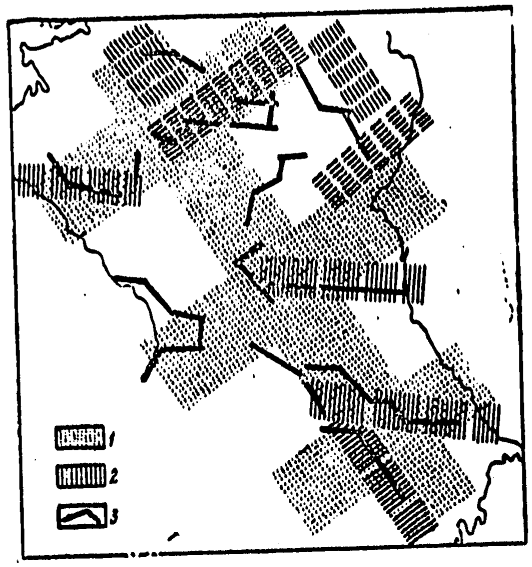


Fig. 5. Main Fault Dislocations of Various Ranks Which Govern the Contrastivity of Recent Tectonic Movements in the Caucasus.

Key: 1. First-rank fault dislocations
2. Second-rank fault dislocations
3. Third-rank fault dislocations (further explanation in text)

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HYDROGEOSEISMOLOGIC[1] PRECURSORS OF EARTHQUAKES

Tashkent UZBEKSKIY GEOLOGICHESKIY ZHURNAL in Russian No 2, 1979, pp 3-13

[Note: Article by A. N. SULTANKHODZHAYEV, Institute of Seismology, Academy of Sciences, Uzbek SSR submitted 10 Aug 78]

[Text] In recent years, increasing attention has come to be given by researchers in the area of earthquake prediction to various hydrogeochemical and hydrogeodynamic effects related to processes which precede and accompany earthquakes. This interest is caused by the fact that, as a result of studies of the Tashkent earthquake of 1966 and it's aftershocks, for the first time researchers succeeded in showing the significance of hydrogeochemical data for the study of tectonic processes. Scientists in Tashkent and Moscow demonstrated the "phenomenon of alteration of the chemical and gas composition (elements and isotopes) of subterranean water during the period preceding and accompanying the earthquake," thus providing a possible method for prediction of the time of destructive earthquakes.

The results of systematic hydrogeoseismologic observation since 1965 through today have confirmed the possibility of using certain hydrogeochemical and hydrodynamic parameters as search criteria for the prediction of earthquakes [5, 6]. Hydrogeochemical anomalies were noted just before the Tashkent earthquake (April, 1966), the Dagestan earthquake (1970), the Iskanderskiy earthquake (1971), the Yangiyul'skiy quake (1972), the Alayskiy quake (July, 1974), the Gazliyskiy quake (April, 1976), the Isfara-Batkentskiy quake (January, 1977), the Tavaksayskiy quake (December, 1977), and the Alayskiy quake (November, 1978). Therefore, hydrogeoseismologic studies have become generally recognized and are under way in many seismically active zones of the Soviet Union.

Systematic work on the search for the precursors of earthquakes by hydrogeoseismologic methods is presently being conducted in the USA (H. Craig, I. Freidman, R. Kovacz), Japan (Hirosi, Vakito, Sariama

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[1] Hydrogeoseismology is a young branch of geologic science, born at the junction of two areas of earth science — hydrogeology and seismology. The primary task of hydrogeoseismology, in its current state of development, is the study of natural seismic phenomena by methods of hydrogeology, including problems of artificially caused earthquakes, the prediction of earthquakes and determination of the force of earthquakes which have occurred.

Mitsu, Aioki Tohia), Italy (M. Del-Aglio, et. al.), China and other seismically dangerous regions of the earth. However, researchers are using various methods and different hardware, making comparative analysis of the results of hydrogeoseismologic studies and their unambigious interpretation difficult. Therefore, no scientifically well founded theory has been developed to explain the nature of the hydrogeochemical and hydrodynamic anomalies which arise before and during strong earthquakes. It is beyond doubt that the natural equilibrium between the rock, subterranean water and gases is disrupted due to the breakdown of the structure of the rock, and that jointed zones appear as the rock accumulates elastic deformation in preparation for an earthquake. It seems to us that the primary factors in the development of the hydrogeochemical anomalies observed must be:

1) Crack formation, facilitating a change in the general gas-chemical composition of the subterranean water and its physical parameters;

2) Ultrasonic oscillations arising during crack formation and facilitating the liberation of gases and chemical elements from the rock and acceleration of processes of their migration;

3) Rising of gases and fluids from the deeper levels of the earth. This factor has been confirmed by combined studies of hyperthermal sources in Central Asia. Since all of these conditions require further clarification and scientific foundation, we must develop the theoretical principles of the mechanism of formation of hydrogeochemical and hydrodynamic anomalies and determine reliable hydrogeoseismologic precursors. Successful performance of this task requires the organization of a hydrogeoseismologic service in each natural-history area, with a processing and warning center. The creation of this sort of service will allow, at the time of appearance of great anomalies, determination of the regions where a possible earthquake might occur, its force and probable time and, in case of danger, transmission of information to the authorities concerning the greatest earthquake threat.

At the present time, systematic hydrogeoseismologic studies are being conducted in Uzbekistan in the Tashkent, Fergana and Kyzylkumy geodynamic areas, using a regional network of existing wells.

Let us discuss some of the results of several years of hydrogeoseismologic studies in the Tashkent geodynamic test area.

The Tashkent geodynamic test area, created after 1966, is located near Tashkent in the Uzbek SSR. This area is used for the conduct of seismologic, geologic-tectonic, engineering-geologic, geophysical, geodetic, hydrogeochemical, hydrodynamic and other types of research operations.

The most important seismotectonic zone in the Tashkent region is the Poltoratsko-Syrdar'ya anticline, located on a continuation of the Ugam-Karzhantauskiy seismotectonic zone. In this area, the epicenters of a number of earthquakes have been concentrated (the Pskint earthquake of 1957, the Brichmullinskiy earthquake of 1959, the Tashkent quake of 1966, Tashkent, 1972 and Tavaksay, 1977).

The Pskint-Brichmullinskiy and Tashkent epicentral zones are presently most seismically active. Hydrogeologically, Tashkent and its environs are a part of the Tashkent artisan basin, within which three structural-hydrogeologic zones can be distinguished; each of these is further subdivided into water-bearing systems and horizons. The Senoman water-bearing horizon of upper Cretacous deposits, a part of the middle level, is one of the most thoroughly studied. Here are the large capacity thermal artisan wells of slightly mineralized water. The system of deposits which includes this horizon is an interstratified mass of sand and gravel formations, clay and aleurites. The depth of the water-bearing horizon varies from 1,300 to 2,400 m. The water in the wells is fresh, primarily of sodium bicarbonate composition, with a high content of chlorides. All of the wells are artisan, with excess pressures at the well head of up to 8 atm and temperatures up to 70 C. The high temperature and unique chemical composition of the water give it excellent balneologic qualities, and have resulted in the extensive practical use of the Tashkent mineral waters. More than 20 thermal mineral water wells have been drilled in the Usbekistan portion of the Tashkent artisan basin; several of these are being systematically observed.

Steady observation of changes in the gas composition (He, Ar, $H_2$, $CO_2$, $N_2$ and Rn), macrocomponent composition (Na, Ca, Mg, Cl, $SO_4$, $HCO_3$, mineralization), microcomponent composition (F, $HBO_2$, Hg, Si), isotope composition ($C^{13}/C^{12}$, $Ar^{40}/Ar^{36}$, $U^{234}/U^{238}$) and physical parameters (pressure, temperature, pH, Eh) continues throughout the year (daily or weekly). Most of these determinations are done by batch methods, the labor consumption and time required for the analysis often limiting sampling frequency. The quality of the information produced depends directly on the care with which the water and gas samples are taken and errors made in analysis. Therefore, generation of the most reliable hydrogeochemical information would require maximum automation of the recording of the parameters studied directly at the well heads, and electronic transmission of the information to the processing center. Therefore, the Laboratory of Hydrogeochemistry of the Institute of Seismology, Academy of Sciences UzSSR, has designed an experimental continuous automatic device for measurement of the concentration of radon in subterranean water — the SANSRR.

Presently, several wells in Tashkent and the Fergana valley have been equipped with improved continuous automatic radon concentration measuring devices. Also, an installation for measurement of the redox potential is in continuous operation around the clock in the village of Ulugbek. Data on the variations of these two parameters are transmitted by telemetry directly from the well heads to a laboratory located 25 km from the point of observation. It is planned for the future to equip all reference points of the hydrogeoseismologic observation network with automatic instruments for the recording of the most informative earthquake precursors, in order to produce the most accurate possible information on variations in various parameters of the subterranean waters.

In the Tashkent geodynamic test area, as a result of systematic observations of individual parameters of the subterranean water, the normal geochemical background of the water-bearing horizon and the behavior of each parameter during relatively quiet and active periods, in the seismic respect, has been determined.

In this geodynamic area, geochemical anomalies can be followed using a broad spectrum of indicator elements (including carbon, nitrogen, hydrogen, chemically neutral radiogenic gases: helium, argon and radon; radioactive substances: uranium, radium, and also trace elements: fluorine, mercury, chlorine, etc.), indicating the commonness of changes in the hydrogeochemical situation. These changes are periodic over time and correlate with the activity of tectonic processes. The hydrogeochemical indices can be divided into classes of indices which precede and which accompany tectonic earthquakes on the basis of their chemical activity and differences in migration capacity.

The first class, those that precede earthquakes, includes the inert gases, hydrogen, nitrogen, carbon dioxide and their isotopes, some relatively abundant and some trace components: chlorine, fluorine, mercury, silicon, boron, which, when the thermodynamic situation changes, may be transformed from the dissolved to the gaseous state, thus increasing their migration capacity. The second class includes the radioactive elements (uranium and its isotopes), the macrocomponent composition and mineralization of subterranean fluids. The farther the hypocenter of an earthquake from an observation point, the less contrast is seen in the hydrogeological changes, and the greater the delay of arrival of information to the observation point. For example, water from a well in the village of Ulugbek, which was of sodium bicarbonate composition prior to the Tashkent earthquake of 1966, shifted to a sodium chloride-bicarbonate composition after the earthquake. The composition changed gradually, over the course of three months, due to an increase in chlorides, accompanied by an increase in total mineralization (from 0.93 g/ℓ in March of 1966 to 1.2-1.3 g/ℓ in 1967-1968). The change in the chemical composition is explained by the arrival of fluoride subterranean water from the Paleozoic to the Senoman horizon in the fracture zone [5]. This water reached the well at Kibray two to three months after the earthquake, and other wells still later, since the movement of the subterranean water depends on the hydraulic slope, the seepage properties of the rock containing the water and the presence of jointed zones. The content of radiogenic gases (radon and helium), however, increased sharply just before and during the earthquake of 1966 (Rn by a factor of 3-4, He by a factor of 12). The reliability of this precursor depends on the magnitude of the upcoming earthquake, the mechanism of its focus and its distance from the observation point. Therefore, before beginning to determine hydrogeochemical effects which precede an earthquake, one must properly select the seismologic material to be gathered. One prerequisite to selection is interpretation of the nature of the focus of the earthquake, which is the volume of material undergoing irreversible deformation. The process of preparation for an earthquake changes the effective physical-mechanical properties of the medium, since it is characterized by a specific space-time course of liberation of seismic energy and represents the basis of the possibility of prediction of the location, time and force of an earthquake. The gas-hydrogeochemical anomalies which precede an earthquake, like others, are caused by the degree and speed of deformation of the rock participating in preparation for the earthquake.

With increasing distance from the focus, the deformations decrease in proportion to the size of the earthquake focus. Based on the experience of processing of hydrogeochemical information in order to locate prognostic anomalies, we searched for a correlation between anomalous variations in the gas-chemical composition and earthquakes, using representative earthquakes which had occurred at distances not over 10 times the seismic focus of the earthquake from each observation point. The quakes used were the Tashkent quake with K = 9, 2 September 1972, the Zaalayskoya quake with K = 16.5 (M = 6.4-6.9) of 11 August 1974, the Gazliyskoya quake with K = 16.5 and 17 (M = 7 and 7.2) of 8 April and 17 May 1976, the Isfara-Batkentskoya quake with K = 15.5 (M = 6.3) and the Tavaksayskoya quake with M = 5.0 of 6 December 1977. The effect of each of these quakes in Tashkent was at least 4 arbitrary scale units.

As the results of processing of the data of observations between 1972 and 1978 indicate, the preparation for each strong earthquake is characterized by a group of anomalous variations in individual parameters, frequently not of equal significance for each of the wells observed, which is related to the depth of deposition of the water-bearing horizon, the presence of fault zones around the well and their distance from the focus of the earthquake [6].

The study of the nature of variation of the gas composition with time is worthy of particular attention, due to the ease of recording of these parameters, as well as the ability to produce interesting information on deep tectonic processes which participate in the preparation for earthquakes. Long-period (2-3 months) variations, consisting of a gradual decrease in the concentration of carbon dioxide gas and helium and sudden changes (from the normal background level to disappearance) in molecular hydrogen, with a subsequent increase and rapid return to previous values immediately after a shock are characteristic for the period of preparation of distant (up to 500 km, Gazli, Alay) "transit" high energy (class 16-17) earthquakes. The duration of the anomalous variations may increase to 4-7 months, when 4-5 strong shocks follow each other within a period of one or two weeks. The amplitude of the anomalous variations is 3-5 times greater than the amplitude of changes in gases during relatively seismically "quiet" periods of observation.

The behavior of the gas components before transit shocks with epicenters within a radius of 200-300 km, but of somewhat lower force (K = 13-15) (Isfara-Batkentskoye) differs in the sharper nature of the anomalous variations. The duration of the decrease and increase in gas concentrations is not over oen or two months. The minimum concentration of gases, or their total absence (hydrogen), occurs one to two weeks before the shock or during the quake. The reaction of the gases to local shocks within the limits of the Tashkent test area (Tashkent, Tavaksay with epicenter distances of up to 50 km) is more rapid and is characterized by a briefer anomalous course as a function of the distance and the force of the shock. The duration of the anomalies is not over 10-20 days.

The experimental results (Figure 1) show the nature of the change in concentration of radon in thermomineral water. The curve of the variations was constructed according to information taken directly from the tape of a strip-chart recorder (time interval between points 3 hours). The characteristic features of the variations are as follows:

1) The concentration of radon reaches its minimum value by 12 May 1976;

2) The nature of the daily variation changes between the 12th and the 13th, and a sudden increase in its concentration is noted;

3) The concentration of radon reaches its maximum between the 14th and the 15th;

4) A decrease in the concentration of radon occurs between the 15th and the 24th;

5) Between 25 and 26 May, the previous values are established, close to the background level. The Gazliyskoye earthquake occurred on 17 May 1976, corresponding to the decrease in concentration of radon (on the 13th). Two large depressions are observed in the curve of the change of concentration of radon as a function of time after the earthquake (Figure 2): the first — in December of 1976, January, February and early March of 1977; the second — during the second half of October, November and the first half of December, 1977. During relatively quiet periods, the concent of radon dissolved in the subterranean water corresponds to mean daily values of 10-12 pulses per second, the amplitude of the variation not exceeding 2-3 pulses per second. Beginning in early December, 1976, the concentration of radon began to drop rapidly and, within 20 days, reached 5-6 pulses per second. The amplitude of variations doubled, the minimum concentration of 4-6 pps was recorded after the strong shock of the Isfara-Batkentskoye earthquake of 31 Jan 1977. Beginning in mid-March, the concent of radon increased sharply and stabilized at the normal geochemical background level. The Tavaksayskoye

earthquake was characterized by a rapid, deeper decrease. During the course of 10 days, the content of radon dropped by a factor of 3. Restoration of the normal geochemical background level also occurred more rapidly than was observed after the Isfara-Batkentskoye earthquake.

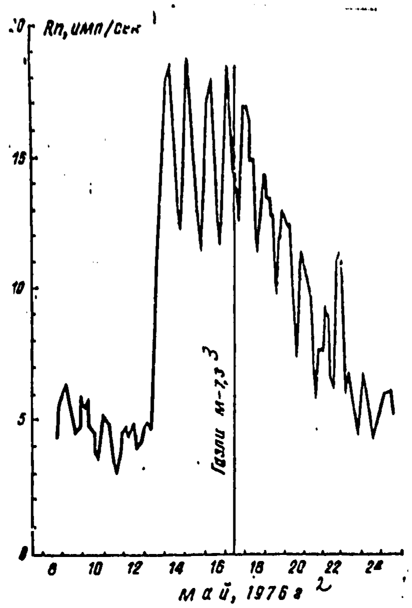


Figure 1. Curve of variation of radon in Ulugbek well around time of Gazli earthquake (17 May 1976).
Key: 1, Rn,pps; 2, May, 1976; 3, Gazli M = 7.3

As we know, with otherwise equivalent conditions, the greater the magnitude of an upcoming earthquake, the greater the deformation of the rock, and the deeper the focus, the greater the area over which deformations propagate. Obviously, this is related to variations in the nature of the anomalous variations, which correlate with strong earthquakes.

The amplitude of the variations in content of radon is inversely proportional to the distance between the location of the earthquake and the point of observation and directly proportional to the force of the shock. Therefore, observations of the variation in the content of informative hydrogeochemical precursors at several points can contour the region where the earthquake is developing and determine the force of a future earthquake. Before the Gazli earthquake, the content of several hydrogeochemical parameters changed in all the wells of the Fergana and Tashkent geodynamic test areas, including an increase in the content of radon [10]. Figure 3 shows the general course of the variation in radon in the zone of the epicenter, in Tashkent and in Andizhan around the time of the Gazli earthquakes. The graphs how the values of the ratios of the measured content of radon ($N_m$) to the background content ($N_{av}$), showing the inverse proportionality of the change in content of radon as a function of distance between the point of observation and the epicenter of the earthquake. The smallest variations are observed at Andizhan (720 km from the epicenter), the greatest — in the epicentral zone.

After processing the material mathematically, one can construct an algorithm and perform the task of predicting the location and force of an expected earthquake. The first experience in processing the results of observations for three points convinces us of the need to organize a hydrogeoseismologic service with a sufficient number of uniformly located observation wells over the region.

It should be noted that the gas-hydrogeochemical anomalies found in the process of this work result from the geotectonic regime of the location. During periods of increasing seismic activity, the so-called process of "gas restoration of the earth," which actually involves a number of different processes in which a mobile equilibrium is achieved between the gases sorbed by the rocks, spontaneously liberated and dissolved in subterranean fluids, is disrupted. Disruption of the equilibrium of the gas-water mixture due to physical-chemical factors leads to free and diffusion of migration of gases through pores and cracks. We can assume that, under these conditions, the intensity of the gas flow increases, not only due to disruption of the dynamic equilibrium in the rock-water-gas system, but also due to gas emanations from the deeps, i.e., the so-called "juvenile gas restoration of the earth." This is indicated by the sudden increase in molecular hydrogen and the sudden decrease, to the point of negative values, in the redox potential just before the Tavaksay earthquake, as well as the results of studies of the isotope ratios of argon and carbon.

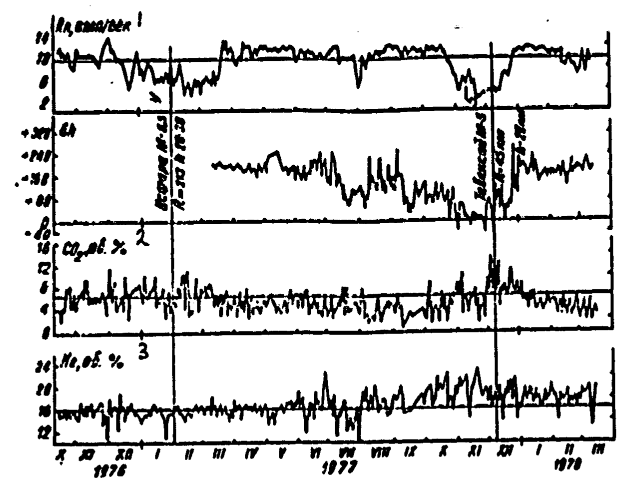

Figure 2. Change in gas-chemical composition of subterranean waters in the Tashkent geodynamic test area during the Isfara and Tavaksay earthquakes.
Key: 1, Rn, pps; 2, $CO_2$, vol. %; 3, He, vol. %; 4, Isfara M = 6.5
5, Tavaksay M = 5.

In addition to the change in gas flow, there is also a variation in the isotope composition of a number of elements — carbon, argon, helium et. al. [7, 8]. Determination of the nature of the variations in isotope composition of gases allows us to generate the greatest quantity of interesting information as a result of systematic observation of the isotope ratio of carbon $C^{13}/C^{12}$ in dissolved carbon dioxide.

Background values of $\delta C^{13}$ have been produced, and in a number of cases significant changes in the values of $\delta C^{13}$ have been recorded, correlating quite well with earthquakes and variations in the content of $CO_2$, He, Rn and $H_2$ in water (Figure 4).

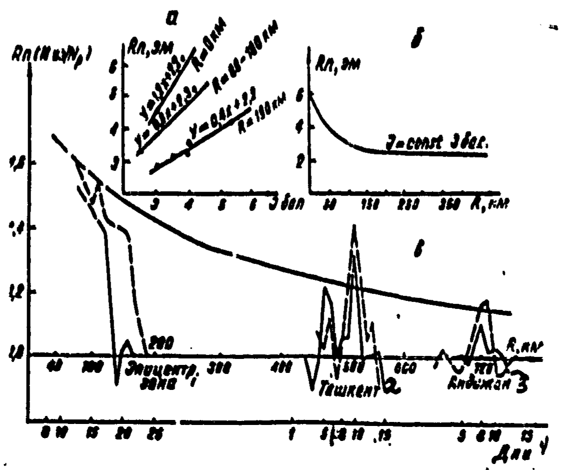

Figure 3. Graph of variation in radon content with force and distance from epicenter of earthquakes and placement of observation point.
Key: 1, Epicenter zone; 2, Tashkent; 3, Andizhan; 4, Days.

Our suggestions do not exclude the importance in the changes of $\delta C^{13}$ of the effect of thermodynamic fractionation. Furthermore, variation in $\delta C^{13}$, in addition to increasing the total concentration of $CO_2$, may result from influx from deeper levels in the crust. It has now been experimentally proven that the so-called "endogenous" carbon dioxide contains carbon enriched in the isotope $C^{13}$. According to many authors [1, 2], endogenous carbon dioxide manifests values of $\delta C^{13}$ = 0.5-0.7%, which may significantly influence the background values of $\delta C^{13}$, causing an increase. Obviously, this hypothesis can only be confirmed by observation of other deep factors. These might include the isotopes of helium ($He^3/He^4$), argon $Ar^{36}/Ar^{40}$ and other radioactive elements. The correlation of these parameters may possibly facilitate solution of this problem.

Measurement of the isotope ratio of $Ar^{40}/Ar^{36}$ in the gases of thermal waters of the Tashkent basin in 1975-1978 revealed certain variations in the content of radiogenic argon (0.05-10%) and the isotope ratio

$(He^4/Ar^{40})_{rad}$ from 12 (during a period of seismic activity) to 150 (during a seismically quiet period [8]).

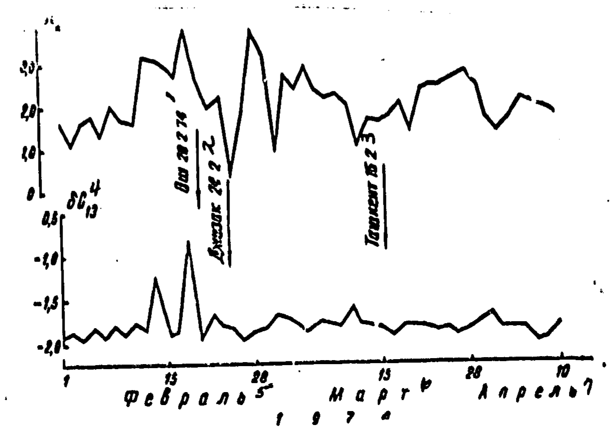

Figure 4. Variations in $\delta C^{13}$ and concentration of $CO_2$ in well 2 (Pobeda Park).
Key: 1, Osh 22 74; 2, Dzhizak 24 2; 3, Tashkent 16 2; 4, $\delta C^{13}$;
5, February; 6, March; 7, April

Since measurements were performed in parallel in two wells, it is interesting to note the correlation. The calculation linear correlation coefficient r = 0.77±0.06; consequently, we can assume that at least 60% of the variability in the flux of $Ar^{40}{}_{rad}$ results, in our opinion, from seismic phenomena. The earthquake in Tavaksay had a particularly great influence on the content of $Ar^{40}{}_{rad}$, since the distance to the epicenter was 25 km.

Thus, we believe that the observed variations in the content of $Ar^{40}{}_{rad}$ and the isotope ratio $(He^4/Ar^{40}{}_{rad})$ result from the influence of tectonic earthquakes in the territory of Central Asia during the period of the investigations.

We must also mention some interesting data obtained as a result of systematic observation of changes in stratal pressure with the purpose of locating precursors [9]. Hydrologic mode observations over the past years have indicated that in rapid extration of thermal mineral waters of Tashkent will lead to a decrease in their excess pressure.

To analyze the change in this parameter over time, we used the gradiant of pressure as a derivative of the value of pressure P with respect to time t. During the period of observation, grad $P = \frac{\partial P}{\partial t}$ was, on the average,

$1.4 \cdot 10^{-3}$atm/day. However, in 1976-1977, this quantity increased by 50%, i.e., the rate of decrease of pressure was $2.1 \cdot 10^{-3}$.

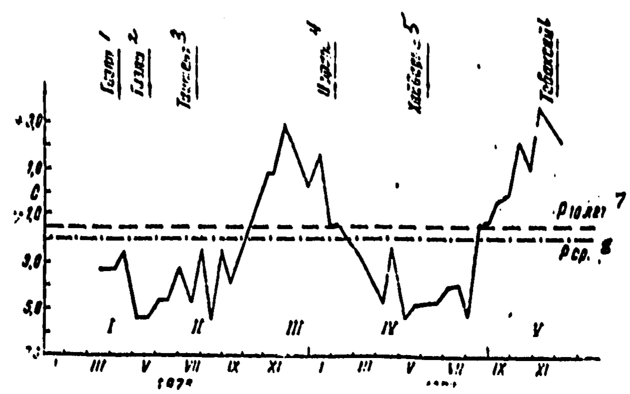

Figure 5. Change in pressure gradiant with time for 1976-1978.
Key: 1, Gazli; 2, Gazli; 3, Tashkent; 4, Isfara; 5, Khaydarke;
6, Tavaksay; 7, P 10 years; 8, $P_{av}$.

Beginning in 1976, when Ulugbek well was taken out of use and systematic daily observations began to be performed in this well, it became possible to analyze the nature of the decrease in pressure in detail.

Figure 5 shows a graph of the pressure gradiant as a function of time. The gradiant was calculated twice per month at a 15-day interval.

During some periods, the rate of decrease of pressure became even greater — $4\text{-}5 \cdot 10^{-3}$, but there are also time intervals during which the gradiant was positive: $2\text{-}3.5 \cdot 10^{-3}$, i.e., the excess stratal pressure increased during these intervals.

Two variations stand out against the background of generally decreasing excess stratal pressure, and both coincided with large earthquakes occurring at Isfara and Tavaksay. The hydrodynamic effects reacted identically to the two earthquakes, which were of approximately equal energy. The difference in the increase in pressure, $\Delta P_2 = 0.1$ atm in the first case and $\Delta P_2 = 0.2$ atm in the second case, results from the difference in the distance from the focus of the two earthquakes to the point of observation.

THus, the variations in excess stratal pressure which we observed result from changes in the stress in the water-bearing horizon due to the preparing earthquake foci.

In conclusion, we must note that the list of hydrogeoseismologic observations which we have presented does not exhaust the list of possible earthquake precursors. This list is rather broad and varied for each natural historical region, within which such observations will be performed. However, positive results of earthquake predictions can be achieved by systematic combined observations of the variations in hydrogeochemical, hydrogeodynamic, hydrogeothermal and other geophysical indicators. The affirmation of some researchers of the possibility of predicting earthquakes by the radon method alone is not confirmed by our years of observations. The correctness of the combined method was demonstrated once more by G. Yu. Azizov et. al., (UzSSR Academy of Sciences Institute of Seismology), who rather accurately predicted the place and time of the Alayskoye earthquake of 2 November 1978.

Doubtless, hydrogeoseismologic work is in its formative stage and it is as yet difficult to predict the location and force of earthquakes using the data observed at scattered stations.

Subsequently, we must organize a service based on a reference network of hydrogeoseismologic stations and points of observation with a single center for processing information and issuing warnings for each seismically active region, at which stations the hydrogeoseismologic data will be compared, correlated and combined with other methods of searching for the precursors of strong earthquakes.

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[1870]

## III. UPPER ATMOSPHERE AND SPACE RESEARCH

### News

MOSCOW OFFERS TO LAUNCH INDIAN COSMONAUT

Paris AIR & COSMOS in French No 771 (23 Jun 79) p 84

[Unsigned article: "An Indian Astronaut in Space?"]

[Text] The USSR has just offered to send an Indian cosmonaut into space in 1980 even though New Delhi had not at present expected such a mission. The proposal was made by President Leonid Brezhnev to Prime Minister Moraji R. Desai on 12 June during his visit to Moscow for the launching of the first Indian earth observation satellite "SEO-1" ("Bhaskara-1") by a Soviet rocket.

On the same day the Soviet Union concluded an agreement with India to launch the Indian "SEO-2" ("Bhaskara-2") satellite, which will be the second flight model of the Indian earth observation satellite. The launching of "Bhaskara-2" is expected in November 1980. It will be the third Indian satellite to be launched by the USSR.

[1853/5]

AIR & COSMOS PREDICTS NEW SPACE ENDURANCE RECORD

Paris AIR & COSMOS in French No 771 (23 Jun 79) p 84

[Article by P. L.: "USSR: Towards a 190-Day Space Flight?"]

[Text] The crew of the Soviet "Salyut-6" orbital station, Vladimir Lyakhov and Valeriy Ryumin, passed the 100-day mark on 5 June, evidently without any major difficulties.

On the next day, 6 June, the USSR launched the unmanned "Soyuz-34" transport ship, which on 8 June docked at the aft end of the station freed when the "Progress-6" cargo ship was undocked.

One week later, on 14 June, the "Salyut-6" crew entered "Soyuz-34" for a brief flight while the station was turned in order to redock the vehicle at the forward docking unit, which was left open when "Soyuz-32" was returned to earth not with a crew but rather with various pieces of equipment and samples from the French ELMA materials processing experiment.

This maneuver will make it possible to dock future "Progress" ships at the aft end of the station in order to resupply it with food, equipment and fuel, as well as to use "Progress" engines for orbital and attitude corrections.

Since the orbital lifetime of the new "Soyuz-34" ship is about 3 months, it is possible, in principle, and if all goes well, for the present "Salyut-6" crew to spend 190 days in orbit and thus to surpass the previous world space endurance record set last year by Vladimir Kovalenok and Aleksandr Ivanchenkov on board the "Salyut-6." [5]

[1853/4]

AIR & COSMOS COMMENTARY ON RECOVERY OF "SALYUT-6" MISSION

Paris AIR & COSMOS in French No 771 (23 Jun 79) pp 86-87

[Article by Albert Ducrocq: "The Sky's Gold"]

[Excerpt] The Soviet Recovery. The Americans are working on the shuttle, the Europeans are readying the "Ariane," and the Russians are developing a manned vehicle of a new type, one that would make a horizontal reentry (this vehicle has already been tested on several occasions and most recently on 23 May under the designation "Cosmos-1100"-"Cosmos-1101."

In the meantime, the USSR continues to make use of conventional configurations without having various "incidents" become "accidents."

The crisis of the past weeks has been surmounted. After the failure of the Soviet-Bulgarian mission in April and the cancellation of the Soviet-Hungarian mission at the beginning of this month, the worst could have been expected. Would it be that "Soyuz-32" would be unusable while the "Progress" freight transport ship docked at the other end of the station could not be separated on 1 June as planned?

The way the operation was executed testifies to the domination of a mature Soviet space technology over the difficulties of today.

After "Progress-6" was used on 4 and 5 June to transfer "Salyut-6" into a 358 x 371 kilometer orbit, on 6 June "Soyuz-34" was launched without a crew.

This explains why the docking of "Progress-6" was prolonged: it placed the space complex into a rendezvous orbit. But at the same time, observers were still intrigued. While "Soyuz-34" was racing through space, both "Salyut-6" docking units were occupied: where would the new vehicle dock?

Various pessimistic commentaries simply eliminated the possibility of docking: it was thought that "Soyuz-34" would only approach "Salyut-6" and that the crew would attempt -- at the price of an EVA -- to join it after a line had been cast between the two vehicles...

Fortunately, the Soviets are far from being reduced to this extreme. They adhered to the idea of keeping "Progress-6" docked to "Salyut-6" as long as possible, and there were no problems with its undocking, which took place on 7 June.

And on the next day, 8 June, at 2002 hours, the "Soyuz-34" docked without difficulty to the aft end of the station. Docking took place during the 33d orbit in accordance with the scenario which, in the past, had been reserved for automatic vehicles ("Soyuz-20" or "Progress").

The Soviet press explained that a modified "Soyuz" had been launched and that in the eight weeks since the failure of the "Soyuz-33" mission a number of changes had been introduced. The Soviets were able to proceed very quickly because they restricted themselves to a small-scale inspection of the "Soyuz," which resulted in only minor modifications to it. This would seem to indicate that during their investigation they maintained the conviction that the malfunction in "Soyuz-33" should not be attributed to a flaw in the design but rather to a specific error in production.

The operation had a double objective. On the one hand, it involved testing of the modified "Soyuz," and on the other hand, furnishing Lyakhov and Ryumin with a new vehicle for their return. The two cosmonauts will test it on 14 June; on that day they will take their places in "Soyuz-34," undock and redock to "Salyut." A statement by Flight Director Cosmonaut Aleksey Yeliseyev implicitly confirmed that "Soyuz-32" would not be used to return a crew to earth: we expect that it will be undocked and burned in the dense layers of the atmosphere like a "Progress," thus freeing a docking unit for "Soyuz-35," which will probably carry the Hungarian cosmonaut whose flight was ultimately only postponed until it could be proven that the station was in ready condition for such a program.

We know that after the Hungarian cosmonauts, cosmonauts from other nations will be flown on board Soviet vehicles. [5]



[1853/6]

SOVIET SPACE COMPLEX EXHIBITED AT PARIS SALON

Paris AIR & COSMOS in French No 769 (9 Jun 79) p 153

[Article by P. L.: "The Soviet Space Complex"]

[Text] The USSR is for the first time exhibiting the space complex which is comprised of three space vehicles: the "Progress-5" freight transport ship (7.2 tons, of which 2.3 tons is cargo), the "Salyut-6" station (18.9 tons), and the "Soyuz-32" transport ship (6.8 tons). The entire complex weighs 32.5 tons and measures 29 meters in length, spanning 17.2 meters (with the solar panels deployed). The USSR has already launched six "Progress" vehicles: 20 January, 7 July, 26 August 1978 and 12 March 1979.

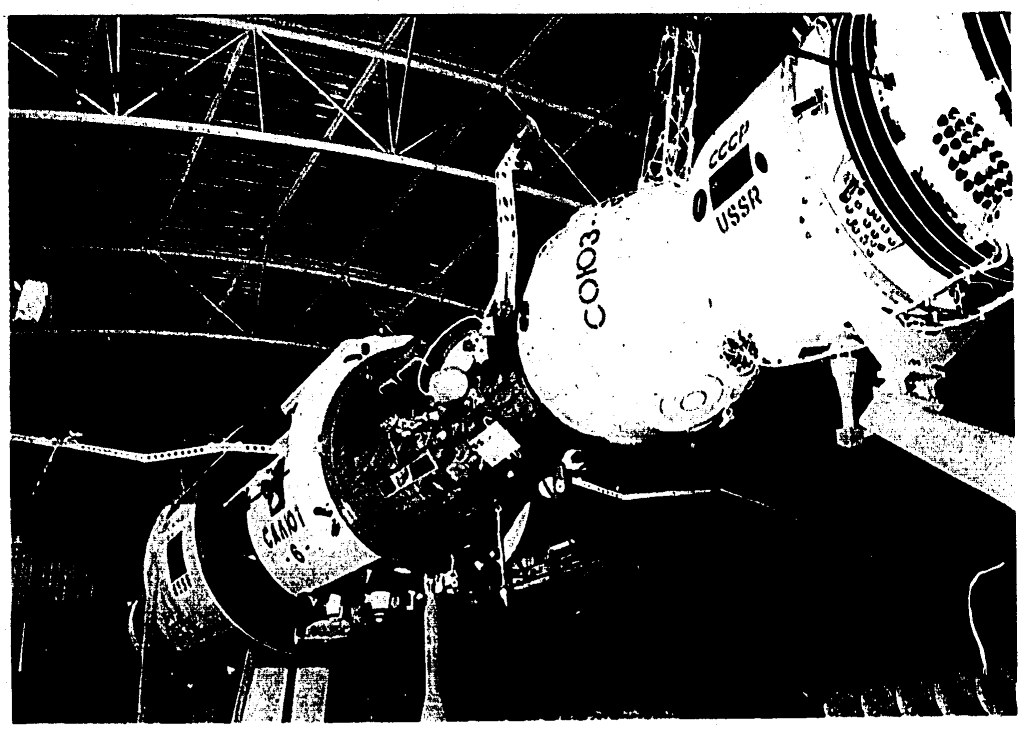


Fig. 1. "Salyut"-"Soyuz"-"Progress" space complex.

Launched on 29 September 1977, "Salyut-6" has received seven crews launched on board "Soyuz" ships 26-32: Yu. Romanenko and G. Grechko 10 December 1977-17 March 1978 (96 days); V. Dzhanibekov and O. Makarov 10-16 January 1978;

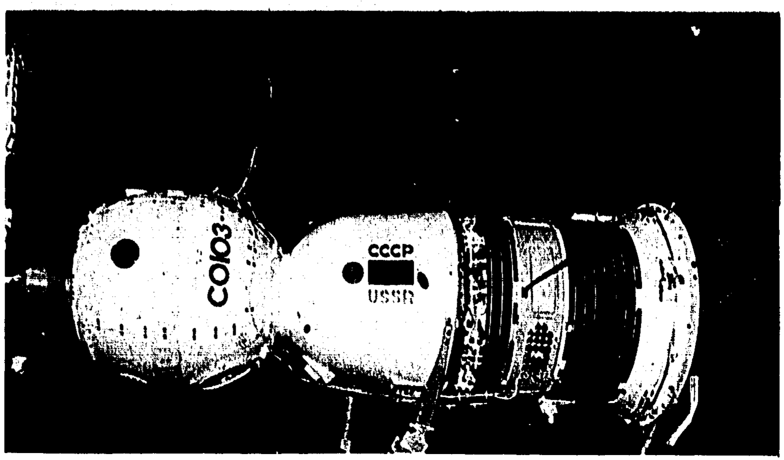


Fig. 2. "Soyuz"

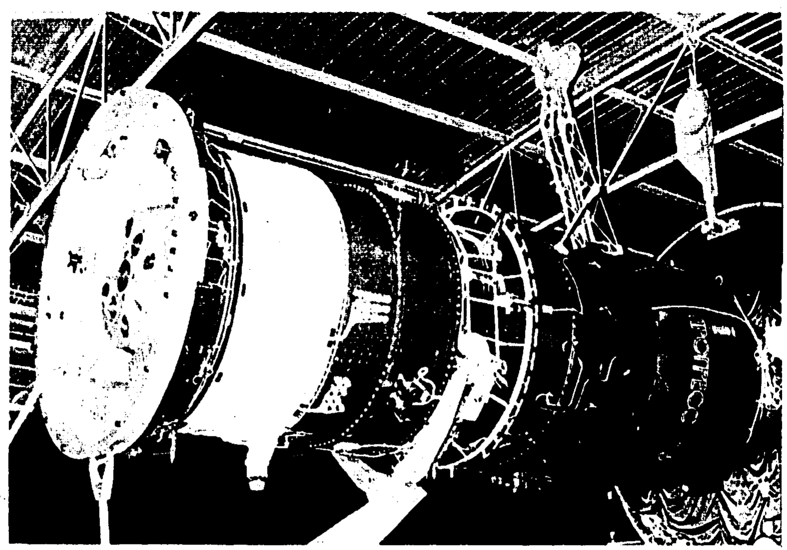

Fig. 3. "Progress"

A. Gubarev and V. Remek (Czechoslovakia) 2-10 March 1978; V. Kovalenok and A. Ivanchenkov 15 June-2 November 1978 (140 days, the world record); P. Klimuk and M. Hermaszewski (Poland) 27 June-5 July 1978; V. Bykovskiy and S. Jaehn (GDR) 25 August-3 September 1978; and finally, V. Lyakhov and V. Ryumin since 25 February 1979 (3 1/2 months). The launch of the next crew, with the first Hungarian cosmonaut, which had been planned for 5 June, has been postponed.



[1853/1]

USSR DISPLAYS NEWEST SATELLITES AT PARIS SALON

Paris AIR & COSMOS in French No 769 (9 Jun 79) p 155

[Article by Pierre Langereux: "'Gorizont,' 'Tsikada' and the 'Vertikal' Probe"]

[Text] The USSR is also for the first time presenting the scientific instrument compartment of the high-altitude astrophysics probe "Vertikal," as well as two new satellites: the "Gorizont" ["Horizon"] satellite and the "Tsikada" ["Cicada"] navigation satellite, which was launched on 31 March 1979 to test the "Shkuna" ["Schooner"] navigation system. There are also a model of "Sputnik-1" and a mock-up of "Luna-24" (launched 19 March 1976) with its recoverable capsule suspended from a parachute. However, the "Meteor-Priroda" ["Meteor"-"Nature"] earth observation satellite was not displayed.

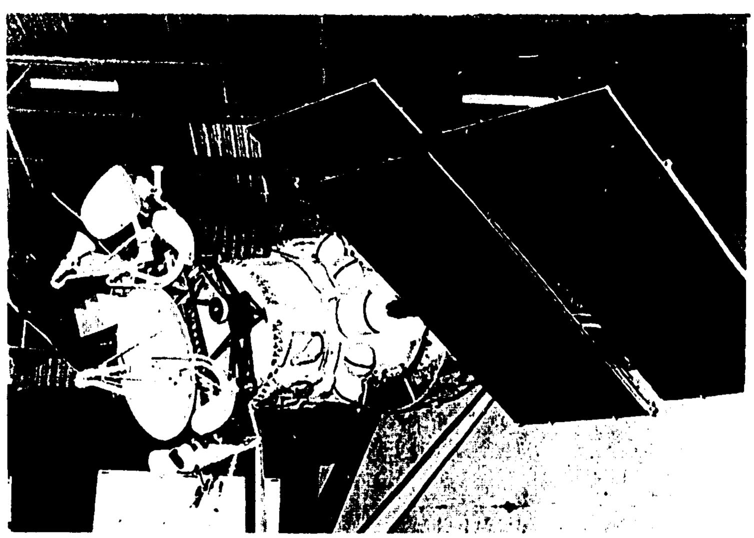

Fig. 1. "Gorizont"

Fig. 2. "Vertikal"

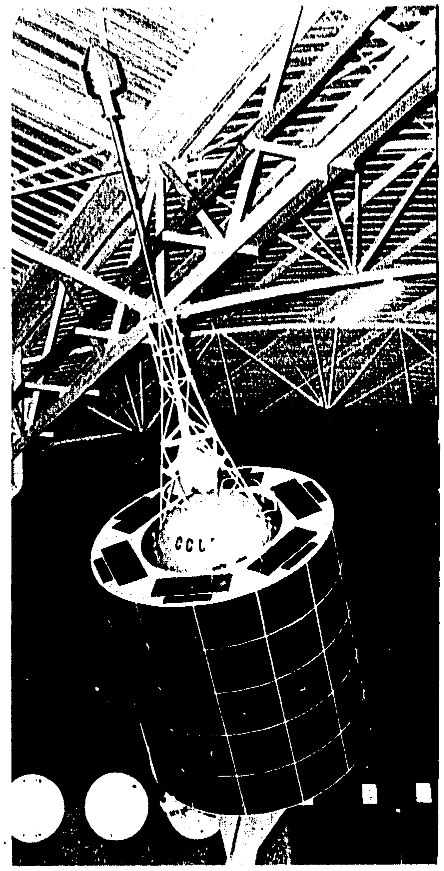

Fig. 3. "Tsikada"

The exhibiting of the "Gorizont" telecommunications satellite is a most impressive event. "Gorizont-1" was launched on 19 December 1978 into a near-synchronous orbit (23 hours 40 minutes) with a perigee of 22,581 km, apogee 48,365 km and inclination 11.3 degrees. It is part of the new operational telecommunications system developed by the USSR to serve the 2-2.5 billion people who will be watching the 1980 Moscow Olympic Games on television. The USSR will be constructing new ground stations around Moscow in order to make use of the "Gorizont" satellites, the "Molniya-2" and "Molniya-3" satellites, the "Intersputnik" network and the Intelsat system.

The USSR telecommunications satellite system is the most important in the world," noted NOVOSTI, "and it continues to expand."

"The development of the national economy in 1976-1980 is based on the use of more and more satellites for television transmission in West and East Siberia (with "Ekran" satellites) and telephone and telegraph service to even the most remote territories."



[1853/2]

AIR & COSMOS COMMENTS ON FUTURE SPECIALIZATION OF SOVIET ORBITAL STATIONS

Paris AIR & COSMOS in French No 774 (14 Jul 79) p 41

[Article by Serge Berg: "Toward a New Flight Record With 'Salyut-6'"]

[Text] The crew of the Soviet "Salyut-6" orbital station — cosmonauts Vladimir Lyakhov and Valeriy Ryumin — will be on the eve of surpassing the space endurance record when these words are published. The Soviet crew, which has been aboard the station since 26 February, has just received a new supply of provisions and fuel which will make it possible to exceed the 140 days spent by cosmonauts Vladimir Kovalenok and Aleksandr Ivanchenkov on board the station last summer.

1.5 Tons of Scientific Equipment

"Salyut-6" scientific equipment includes more than 50 different instruments, representing a total weight of more than 1.5 tons, according to Soviet cosmonauts Yuriy Romanenko and Engineer V. Pozdniak in a recent AVIATSIYA I KOSMONAVTIKA article that also published a diagram of the station (Cf. USSR REPORT: GEOPHYSICS, ASTRONOMY AND SPACE, JPRS 73852 for both the translation and reproduction of the diagram.)

The authors explained that all of the optical instruments and portholes of the station are protected against micrometeorites. KRASNAYA ZVEZDA ("Red Star") on 20 June also devoted an article to micrometeorite collisions, the number of which can vary from one to several dozen per day. The impacts are recorded by three detectors, and in case the hull of the station is penetrated -- which is highly improbable -- an automatic device will make it possible to maintain sufficient air pressure within "Salyut-6" until the cosmonauts can put on their spacesuits.

From Universal to Specialized Stations

Romanenko and Pozdniak also explained that the present trend in the Soviet Union is toward "universal" orbital stations -- capable of dealing with a great variety of missions -- but in the future, as the cost of spaceflight is reduced, it will be oriented toward the specialization of orbital stations.

The diversity of experiments, in effect, complicates the course of operations. Certain astronomical observations require extreme precision in aiming in certain directions whereas other experiments, for example, those in space metallurgy, require "microgravity," which cannot be easily obtained except while the cosmonauts are asleep. This is why the materials processing experiments in "Splav" and "Kristall" are conducted during the crew's hours of sleep. Furthermore, the Soviets have established a schedule of operations: certain days are devoted to astrophysics, others to observations of the earth, and still others to technological experiments.

The authors also expect that a greater continuity could be established for orbital activities. They expect that the time is near when the changing of crews will take place on board the stati itself (at present one crew returns to earth before another arrives to relieve them). Thus, the departing cosmonauts could pass on their instructions and observations to the next crew while still on board the station. This follows along the lines of permanent occupation of Soviet orbital stations. [5]
[1853/7]

Translation

UDC 528.4(201)

# POSSIBILITIES OF OPTIMUM PLANNING OF A MULTIPURPOSE SPACE SURVEY

Moscow IZVESTIYA AKADEMII NAUK SSSR, SERIYA GEOGRAFICHESKAYA in Russian
No 3, 1979 pp 103-110

[Article by K. Ya. Kondrat'yev, A. I. Belyavskiy and O. M. Pokrovskiy, Leningrad University]

[Text] Representatives of many scientific disciplines are participating in investigations of the environment and natural resources by remote sensing from space. Therefore, one of the most important problems in this field is a determination of those requirements on the information content of the collected data whose satisfaction will ensure the broadest possibilities for their multipurpose interpretation. The considered problem can be solved most effectively on the basis of use of the methods of optimum planning of an experiment. By using such methods in the planning of measurements relating to individual problems in remote sensing, it was possible to determine the optimum makeup of the instrumentation in each specific case (Pokrovskiy, Bykov, 1975). Numerous investigations relating to narrow fields of remote sensing made it possible to formulate specific requirements on the corresponding instrumentation and measurement methods.

The range of problems involved in the remote sensing of environmental parameters is constantly expanding. This determines the need for determining optimum schemes for remote measurements for multiple purposes. Since different space vehicles (automatic artificial earth satellites, manned spaceships, stations and complexes) are used as the carriers of scientific instrumentation, the problem for all practical purposes is reduced to the creation of optimum multipurpose measurement complexes ensuring solution of a broad range of remote sensing problems.

In a study by K. Ya. Kondrat'yev, A. A. Grigor'yev and O. M. Pokrovskiy (1975), on the basis of data available in the literature, there was a systematization of the requirements imposed on the results of remote measurements in the interests of oceanology, hydrology, geology, forestry and agriculture. On the basis of this information an attempt was made to determine the requirements on the choice of an optimum set of spectral intervals for a multizonal survey for different classes and complexes of problems (Kondrat'yev, Pokrovskiy, 1977). The basis for the optimization method was the factor analysis (FA) algorithm.

In this paper the authors continue their investigations for the purpose of determining noncontradictory requirements on important instrument parameters and the measurement method (spatial resolution, geometry of sighting, frequency with which surveys are made, illumination conditions, etc.).

Optimization Method

Now we will examine the possibilities of applying the concepts of factor analysis (Lowley, Maxwell, 1967; Harman, 1972) for solution of the multipurpose planning problems.

The requirements imposed on different aspects of a space survey (for example, spectral or spatial resolution, coverage, frequency of survey, etc.) can be expressed quantitatively. Moreover, for each of the considered survey parameters it is possible to mention the corresponding interval of the best values for individual specific purposes (Kondrat'yev, Grigor'yev, Pokrovskiy, 1975).

Our problem is to select the intervals for each of the considered survey parameters which in general would best satisfy the requirements for the groups and classes of problems imposed simultaneously.

Now we will formalize formulation of the optimization problem. Assume that the components of the vector $v_s$ ($s = 1,\ldots,m$) describe a set of requirements on the entire set of survey parameters, determined by the conditions of the individual s-th problem. The method for formalization of the requirements in the form of components of the vector $x_s$ must be the same for all m problems.

In the next section we will discuss the formalization method which we used in solving this problem.

Because of the great number of such requirements the number n of vectors $x_s = x_s^1,\ldots,x_s^n$ is extremely significant. This can also be said about the number of the considered special problems. Our objective is to describe the structure of the sample of vectors $\{x_s\}$ with use of the minimum number of characteristic parameters. Such a problem can be solved effectively using the factor analysis algorithms. In this case the following form of the approximation is used:

$$x_s^i = \sum_{j=1}^{k} a_{ij} f_j + l_s^i \tag{1}$$

where $f_j$ is the j-factor, k is a fixed number of factors, $a_{ij}$ is the load of the j-th factor on the i-th component of the vector x, $l_s^i$ is the remainder. The dimensionality of the factor space k must be substantially less than the initial dimensionality n.

It is known that the optimum approximation method is a representation in the form (1) with use of the "main components" base (Anderson, 1961). A serious shortcoming of such an approach is the circumstance that the matrix of factor loads $A = \{a_{ij}\}$ in the mentioned case does not have any definite structure. Anomalies in the components of the columns of the A matrix are decisive in the choice of the experimental scheme. However, equation (1) remains invariant relative to orthogonal transforms of the factor f = Uf. We have A = UA·U*. Now our problem is, making use of the technique of orthogonal rotations in factor space, to achieve such a position that definite variables have extremal loads on one factor and almost zero loads on the remaining factors (Lowley, Maxwell, 1967).

Now we will formalize the described algorithm. Assume that the k "main components" of the sample $\{x_s\}$ form k columns of the matrix $A = \{a_{ij}\}$ under the condition that

$$\sum_{i=1}^{n} a_{ij}^2 = \lambda_j^2 \, (j = 1, \ldots, k), \quad \text{where} \quad \lambda_1 > \lambda_2 \ldots > \lambda_k$$

are the corresponding eigenvectors. The choice of the matrix of rotations conforms to the condition of maximizing of the functional characterizing the degree of inhomogeneity of the matrix of factor loads:

$$A = \max_{UAU^*}\left(\sum_{j=1}^{k}\left\{n \cdot \sum_{i=1}^{n} (a_{ij}^2/h_i^2)^2 - \left[\sum_{i=1}^{n} (a_{ij}^2/h_i^2)\right]^2\right\}\right)$$

Here $h_i^2 = \sum_{j=1}^{k} a_{ij}^2.$

The rotations methods has been described in the monographs of D. Lowley and A. Maxwell (1967) and H. Harman (1972). The effectiveness of the approximation based on use of the k-factors is described by the value of the relative accumulated dispersion:

$$d_k = \left(\sum_{j=1}^{k} \lambda_j^2 \Big/ \sum_{j=1}^{n} \lambda_j^2\right).$$

The contribution of the k-factor is characterized by the ratio

$$g_k = \lambda_k^2 \Big/ \left(\sum_{j=1}^{n} \lambda_j^2\right)$$

Types of Requirements on Instrumentation and Survey Method

The described FA algorithm was used for the purposes of optimum choice of the conditions for a multizonal survey for a broad set of requirements. A study by K. Ya. Kondrat'yev and A. M. Pokrovskiy (1977) examines the problems relating to choice of the optimum spectral zones. Therefore, here we discuss the remaining parameters characterizing the conditions for carrying out a space survey. Eight types of such requirements are considered:

1) resolution in a detailed survey (RDS); 2) resolution in an overall survey (ROS); 3) minimum solar altitude (SA); 4) maximum sighting altitude (MSA); 5) optimum sighting altitude (OSA); 6) nominal survey periodicity (NSP); 7) maximum survey periodicity (MSP); 8) survey coverage (SC).

Table 1

Ranking of Requirements on Instrumentation and Survey Methods

| No. | Requirements | High | Medium | Low |
|---|---|---|---|---|
| 1. | Resolution in detailed survey, m | 0-9 | 10-30 | 50-300 |
| 2. | Resolution in overall survey, m | 15-60 | 70-100 | 125-1000 |
| 3. | Minimum solar altitude, degrees | 60 | 45 | 15-30 |
| 4. | Maximum sighting altitude, degrees | 0-20 | 30 | 45-80 |
| 5. | Optimum sighting altitude, degrees | 0 | 10 | 20-30-60 |
| 6. | Nominal periodicity of survey | 1 day-20-days | 1 month-4 months | 6 months-5 years |
| 7. | Maximum periodicity of survey | 0-24 | 3 days-20 days | 1 month-4 months |
| 8. | Survey coverage, km | 40-100 | 200 | 400-1000 |

The requirements on the mentioned set of parameters for individual special problems in oceanology, hydrology, geology, forestry and agriculture were outlined schematically in a study by K. Ya. Kondrat'yev, A. A. Grigor'yev and O. M. Pokrovskiy (1975). In this study, on the basis of the cited data, it was possible to determine the structure of the vectors $\{x_s\}$, and also the specific values m and n. Now we will discuss some details in formation of the vectors $\{x_s\}$.

For a systematized description of the totality of all the requirements we used the vectors of $\{x_s\}$ data, whose dimensionality is $n = 89$. Each component $x_s^i$ $(i = 1,\ldots,n)$ assumed the value 0 or 1, depending on the absence or presence of the i-th requirement in the list of requirements for the s-th problem. The total number of vectors $\{x_s\}$ was $m = 73$.

The components $x_s^i$ corresponded in the following way to the parameters of the measurement scheme:

| | |
|---|---|
| RDS:1-13; | OSA:47-51; |
| ROS:14-32; | NSP:52-66; |
| SA:33-37; | MSP:67-82; |
| MSA:38-40; | SC:83-89. |

The application of the FA algorithm, employed with a YeS-1030 electronic computer, in different cases made it possible to discriminate from 7 to 24 factors. First it was assumed that for each factor there would be stipulation of requirements with the greatest "information weight," on the basis of a simple threshold criterion: $|a_{ij}| \geqslant c$ (Kondrat'yev, Pokrovskiy, 1977).

Table 2

Computations of "Information Weights" of Requirements on Instrumentation and Survey Method for Problems in Individual Disciplines

| Задачи и дисциплины 1 | Вид требований 2 | 3 Параметры схемы измерений: РДС 4 | РОС 5 | ВС 6 | ВВМ 7 | ВВО 8 | ПСН 9 | ПСМ 10 | ОС 11 |
|---|---|---|---|---|---|---|---|---|---|
| 12 I — океанология | Высокие 16 | 0,67 | 3,38 | 3,00 | 1,41 | 2,23 | 2,85 | 2,31 | 1,53 |
| | Средние 17 | 2,93 | 4,04 | 0 | 3,66 | 0,88 | 2,17 | 1,37 | 1,56 |
| | Низкие 18 | 3,47 | 2,74 | 0,45 | 1,14 | 3,14 | 2,53 | 1,06 | 2,36 |
| 13 II — гидрология | Высокие | 4,0 | 2,47 | 0,92 | 0,0 | 0,0 | 1,54 | 3,00 | 0,98 |
| | Средние | 2,14 | 2,25 | 0,90 | 2,58 | 0,55 | 1,80 | 2,00 | 1,79 |
| | Низкие | 0,87 | 2,52 | 0,45 | 0,0 | 0,0 | 3,06 | 2,02 | 1,72 |
| 14 III — геология | Высокие | 3,04 | 2,23 | 0,63 | 0,55 | 0,0 | 0,72 | 0,24 | 1,07 |
| | Средние | 2,89 | 4,13 | 0,76 | 2,18 | 1,10 | 1,36 | 2,12 | 2,07 |
| | Низкие | 1,70 | 2,60 | 3,80 | 1,37 | 1,25 | 3,09 | 0,41 | 2,56 |
| 15 IV — лесное и сельское хозяйство | Высокие | 2,88 | 2,32 | 2,84 | 3,90 | 0,0 | 3,18 | 1,25 | 2,66 |
| | Средние | 3,48 | 2,89 | 0,79 | 3,99 | 0,0 | 2,03 | 2,59 | 4,65 |
| | Низкие | 0,0 | 1,25 | 2,70 | 2,01 | 0,0 | 3,69 | 1,03 | 2,70 |

KEY:

1. Problems and disciplines
2. Type of requirements
3. Parameters of measurement scheme
4. RDS
5. ROS
6. SA
7. MSA
8. OSA
9. NSP
10. MSP
11. SC
12. Oceanology
13. Hydrology
14. Geology
15. Forestry, agriculture
16. High
17. Medium
18. Low

However, it was found that for a number of problems not all the components of the matrix of factors $a_{ij}$ satisfied this condition when c = 0.7. However, a decrease in the threshold criterion c did not make it possible to detect the most informative requirements. Therefore, it was necessary to use a different approach: for each type of requirements a classification was made into high, medium and low requirements (Table 1). We will examine the following characteristics of the factors:

$$\eta^l_{ij} = \sum_{k \in h_{ij}} \tilde{a}^2_{kl}/n_{ij}, \quad \xi^{(l)}_{ij} = \frac{\eta^l_{ij}}{\sum_{i'j'} |\eta^l_{i'j'}|}$$

Here $l$ is the number of the factor, i is the number of the measurement scheme parameter (i = 1,...,8), j is the type of requirements (j = 1 -- high, j = 2 -- medium, j = 3 -- low requirements), $n_{ij}$ is the number of requirements arising in special problems and entering, in accordance with the classification into the the "box" (i, j) Table 1, $h_{ij}$ is a set of indices of the vector

Table 3

Computation of "Information Weights" of Requirements on Instrumentation and Survey Methods for Combinations of Problems in Disciplines

| Группа задач * 1 | Вид требований 2 | 3 Параметры схемы измерений | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | РДС 4 | РОС 5 | ЦС 6 | ВВМ 7 | ВВО 8 | ПСН 9 | ПСМ 10 | ОС 11 |
| I, II | Высокие 12 | 2,61 | 2,10 | 1,71 | 0,59 | 0,11 | 2,42 | 2,08 | 0,38 |
| | Средние 13 | 1,04 | 3,44 | 1,85 | 1,76 | 3,53 | 1,57 | 1,20 | 0,91 |
| | Низкие 14 | 2,56 | 1,76 | 0,99 | 0,81 | 2,49 | 1,42 | 0,85 | 1,34 |
| III, IV | Высокие | 2,02 | 1,77 | 1,41 | 1,33 | 0,0 | 2,75 | 0,42 | 1,45 |
| | Средние | 3,45 | 2,41 | 0,61 | 2,45 | 1,56 | 0,58 | 2,72 | 1,81 |
| | Низкие | 1,03 | 1,35 | 2,01 | 2,18 | 2,17 | 4,35 | 1,02 | 1,39 |
| II—IV | Высокие | 4,63 | 3,19 | 1,18 | 0,34 | 0,0 | 2,07 | 2,45 | 1,05 |
| | Средние | 1,04 | 3,83 | 1,00 | 1,54 | 1,82 | 0,91 | 1,53 | 0,38 |
| | Низкие | 0,21 | 2,73 | 0,97 | 1,29 | 0,03 | 2,08 | 0,42 | 1,45 |
| I—IV | Высокие | 0,64 | 1,41 | 1,89 | 1,37 | 0,36 | 2,01 | 1,87 | 0,76 |
| | Средние | 2,60 | 1,45 | 1,36 | 1,83 | 1,63 | 1,14 | 1,35 | 2,36 |
| | Низкие | 1,36 | 0,64 | 1,32 | 1,14 | 3,18 | 2,03 | 1,16 | 1,66 |

KEY:

1. Group of problems
2. Type of requirements
3. Parameters of measurement scheme
4. RDS
5. ROS
6. SA
7. MSA
8. OSA
9. NSP
10. MSP
11. SC
12. High
13. Medium
14. Low

Note: Roman numerals same as in Table 2

$x_s$, corresponding to the pair (i, j). In such a case the relative "information weight" of the considered pair of requirements for the set of all factors is determined using the formula

$$r_{ij} = \sum_l \lambda_l^* \xi_{ij}^{(l)}$$

In this case the optimization problem is reduced to determination of the form of the requirements $j^*$ at which the maximum is attained

$$r_{ij^*} = \max_{ij} \{r_{ij}\}$$

for each parameter i, j of the measurement scheme.

Measurement Scheme for Principal Groups of Problems

Now we will examine the results of application of the algorithm described above for selection of the optimum conditions for a multizonal survey. We will successively combine the initial problems into groups and classes of problems.

First we will combine the problems into four principal groups: I -- oceanology, II -- hydrology, III -- geology, IV -- forestry and agriculture. We then apply the optimization algorithm presented above to the corresponding sets of $\{x_s\}$ vectors. The computation data for the "information weights" $r_{ij}$ are presented in Tables 2 and 3. An analysis of the cited $r_{ij}$ values makes it possible to discriminate several typical situations. We will now discuss them in greater detail.

The most favorable case is when the algorithm makes it possible to define only one type of requirements for the particular parameter. The mentioned situation arises when the "information weight" of the particular type of requirements dominates over the others. For example, for group I of problems it is possible to stipulate high requirements with respect to SA and MSP, medium requirements for MSA, low requirements for RDS, OSA, SC. In the second group of problems high requirements are imposed on RDS, MSP, medium on MSA, OSA, low on NSP. In an examination of group III it is possible to formulate medium requirements for ROS, MSA, MSP, low -- for SA, NSP. For group IV it is possible to stipulate medium requirements for RDS, MSP, SC. An additional examination with use of the "threshold criterion" makes it possible to choose the mean requirements for ROS in problems of groups I and IV.

In a case when the "adjacent" types of requirements (low and medium or high and medium) correspond to close values of the "information weights" the choice of requirements becomes less definite.

For example, for problems in group II SA is determined by medium or high requirements, SC by medium or low requirements. In problems of group III there are medium or low requirements on OSA and SC, high or medium requirements on RDS. For group IV high or medium requirements are imposed on MSA.

A more complex situation arises in a case when high and low requirements correspond to close values of the "information weights." Such a situation holds true for NSP (group I), ROS (group II), SA and NSP (group IV). The ambiguity problem in the choice of requirements requires a separate examination with the use of additional factors (for example, expenditures on the planning and implementation of an experiment).

Thus, together with most parameters characterizing measurement conditions, for which the requirements can be determined unambiguously, individual cases stand out when solution of the problem of planning of an experiment is ambiguous. The requirements are formulated most successfully for problems in oceanology. Here the types of requirements have been determined unambiguously for seven of the eight parameters. For problems in groups II and III there is unambiguous determination of requirements on five parameters, for problems in group IV -- on four survey parameters.

Due to the diversity of requirements formulated for the basic groups of problems, the problem of the possibility of their matching in an examination of complex problems remains open.

Optimum Measurement Conditions in Solving Complex Problems

Now we will examine the possibilities of planning of complex problems in remote sensing (see Table 3). We will begin with an analysis of the conditions for carrying out an experiment for pairs of problems (I, II) and (III, IV).

In the case of a complex problem (I, II) high requirements are imposed on NSP, MSP; medium requirements are imposed on ROS, MSA, OSA; low requirements are put on SC. The result obtained for NSP indicates that with respect to the "information weight" problems of group I dominate over problems in group II. For SA it is possible to use a broad range of high and medium requirements. The contradictory nature of the requirements imposed on RDS in the groups of problems I and II leads to an ambiguity in solution of the planning problem with respect to the mentioned parameter for the combination I, II).

Now we will examine the complex problem (III, IV). Here medium requirements are imposed on RDS, ROS, MSP, SC; low requirements are imposed on SA, OSA, NSP. For MSA it is possible to select medium or low requirements. By comparing the cited data with the results of the analysis made above for the principal groups of problems, we note that in the case of complex problems there is a decrease in the number of parameters planned in a broad range or planned ambiguously.

A problem of considerable practical interest is the planning of an experiment involving investigation of complex natural features on the land. We will examine the complex problem (II, III, IV). In this case high requirements are imposed on RDS, MSP, medium requirements -- on ROS, MSA, OSA, low requirements -- on SC. The contradiction in the requirements on individual groups of problems causes an ambiguity in the recommendations for NSP. The planning algorithm does not make it possible to define any preferable requirements for SA.

A problem of great importance is the possibility of formulating requirements on the measuring instrumentation intended for studying the complex of natural features of the land and ocean. The experimental plan in this case is based on the matching of the requirements of a complex of four main groups of problems (I, II, III, IV). In the considered situation high requirements are imposed on SA, MSP, medium requirements -- on RDS, MSA, SC, low requirements on OSA. The range of high and medium requirements satisfies solution of the problem for ROS. However, due to the contradictory nature of the requirements associated with individual groups of problems, there will be an uncertainty in determining NSP.

Thus, the planning of complex problems did not lead us to a reduction, but to an increase in the number of parameters for which the requirements can be determined unambiguously.

Thus, among the eight considered parameters characterizing the conditions for remote measurements, the choice of the six ROS, RDS, SA, MSA, OSA, SC can be used in effective planning in the solution of complex problems.

Due to the contradictory nature of the requirements imposed by different groups of problems, the parameter of survey periodicity NSP cannot be determined unambiguously. The final solution of the problem of choice of the values of the mentioned parameters must be made with allowance for additional factors.

Analysis of Results and Recommendations

Now we will summarize some results of this investigation. Table 4 gives the results of optimization of measurement conditions both for the basic groups of problems and for the most important complexes of problems in remote sensing. The considered parameters can be divided into the following four groups: spatial resolution (RDS, ROS), geometry of survey (SA, MSA, OSA), periodicity (NSP, MSP), survey coverage (SC). We will analyze the variability of requirements on these parameters with transition from one group of problems to another.

Table 4

Requirements Imposed on Multipurpose Survey

| Group of problems | Parameters of Measurement Scheme | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | RDS | ROS | SA | MSA | OSA | NSP | MSP | SC |
| I | L | M | H | M | L | H,M | H | L |
| II | H | H,M | H,M | M | M | L | H | M,L |
| III | H,M | M | L | M | L,M | L | M | M,L |
| IV | M | M | H,L | H,M | - | L,H | M | M |
| I,II | H,L | M | H,M | M | M | H | H | L |
| III,IV | M | M | L | M | L | L | M | M |
| II-IV | H | M | H,M,L | M | M | L,H | H | L |
| I-IV | M | H,M | H | M | L | L,H | H | M |

Note: Type of requirements: L -- low, M -- medium, H -- high

Spatial resolution. Oceanology imposes low requirements on RDS, but problems associated with study of land features impose high and medium requirements. Therefore, in the planning of a survey in the interests of a complex of problems (II, III, IV) it is necessary to impose high requirements on RDS. General-purpose apparatus for global monitoring of the entire range of parameters for the land and ocean can have medium RDS. Medium requirements on ROS are adequate for almost all problems.

Geometry of survey. Although the contrast between low requirements on SA in the the groups III and IV and the high requirements in groups of problems I and II makes difficult the planning of a complex experiment for the land (II, III, IV), a satisfactory solution of the problem can be found on the basis of high requirements. The choice of medium requirements for MSA is optimum in general with respect to all problems.

In the case of problems in the monitoring of land parameters, low or medium requirements are imposed on OSA. In the planning of general-purpose apparatus we can limit ourselves to low requirements.

Survey periodicity. Due to the lack of rigorous requirements on NSP in groups I and IV an ambiguity arises in the solution relative to NSP for highly important complex problems. Therefore, here it is desirable to select high requirements for NSP. In the main groups of problems either high or medium requirements are imposed on MSP. In the planning of complex problems it is desirable to select high requirements for MSP.

Survey coverage. Individual groups of problems impose medium or low requirements on SC. For complex problems of study of land features it is adequate to have satisfaction of low requirements relating to SC. In the planning of global monitoring of parameters of the land and ocean medium requirements are imposed on SC.

In conclusion it must be emphasized that the results obtained in this study are based on the use of a summary of the requirements on the planning of remote sensing experiments prepared by K. Ya. Kondrat'yev, A. A. Grigor'yev and O. M. Pokrovskiy (1975). This summary must be regarded not only as incomplete and preliminary, but also in some respects incorrect. An important problem which remains is the refinement and "objectivization" of requirements on remote sensing data in the interests of different branches of interpretation of data. Only on this basis can there be a more adequate solution of problems in the optimum planning of multipurpose systems for the remote sensing of parameters of the environment and natural resources.

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[451]

IV. MISCELLANEOUS

Translation

## SOVIET ANTARCTIC EXPEDITIONS SUMMARIZED

Leningrad TRUDY SOVETSKOY ANTARKTICHESKOY EKSPEDITSII: SEMNADTSATAYA SOVETSKAYA ANTARKTICHESKAYA EKSPEDITSIYA in Russian Vol 71 signed to press 12 Dec 78 pp 9-37

[Chapter 1 of book "Trudy Sovetskoy Antarkticheskoy Ekspeditsii" (Proceedings of the Soviet Antarctic Expedition: The 17th Soviet Antarctic Expedition) edited by doctor of geographic sciences Ye. S. Korotkevich, Gidrometeoizdat, Leningrad, 1979, 560 copies, 151 pages]

[Excerpt] Chapter 1. Logistics of the Expedition.

In conformity with the international Treaty on Antarctica, the 17th Soviet Antarctic Expedition continued research begun by our country on the continent and in Antarctic waters according to the program of the International Geophysical Year (see Figure 1 below).

The research in the ocean was a continuation of the study of the state of the water, relief of the sea floor and earths, ice conditions, and distribution of icebergs, the earth's magnetic field, and other phenomena.

Concurrently with studies of the ocean a broad range of observations of the atmosphere above the ocean was made. This involved temperature-wind and actinometric sounding and observations of change in weather conditions. In addition, satellite information was used extensively to analyze the cloud cover of the southern hemisphere and the ice situation in Antarctic waters.

The principal seasonal investigations on the continent involved the comprehensive study of an extremely interesting rock and ice region of Mac-Robertson Coast (the Amery Iceshelf, Lambert Glacier, and Prince Charles Mountains). These investigations included: topographical-geodetic work with aerial photography; geological-geophysical projects envisioning comprehensive study of the geological structure and geophysical field in order to formulate a map of the tectonic zoning of Antarctica and identify regions where useful minerals may be found; biolgoical and geographic study of the region.

Broad investigations of the Antarctic icecap were made during the continental trip from Mirnyy Station to kilometer No 171 for the purpose of

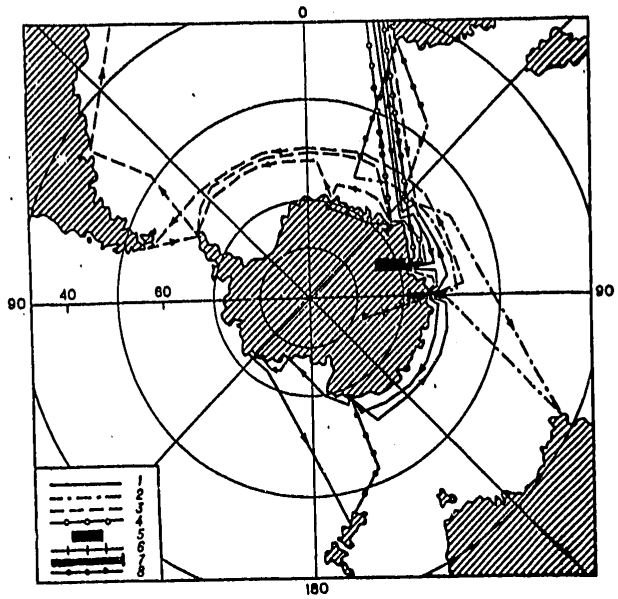



Figure 1. Diagram of Seasonal Work of the 17th Expedition of 1971-72.

Key: (1) Route of the Diesel Electric Ship Ob';
(2) Route of the Research Ship Professor Vize;
(3) Route of the Diesel Electric Ship Navarin;
(4) Route of the motorship Nadezhda Krupskaya;
(5) Region of Astronomical-Geodetic and Geological-Geophysical Projects;
(6) Airplane Flights;
(7) Caterpillar Sled Trips;
(8) Hydrologic Sections.

obtaining data on the thickness of the ice, its structure, chemical composition, temperature state, rate of feeding, direction and speed of movement of the ice, and the relief beneath the ice. A project with autonomous magnetic variation stations was carried out during a transport trip from Mirnyy to Komsomol'skaya. Topographic-geodetic work was also done around the Molodezhnaya Antarctic Meteorological Center, including measurement of a baseline and construction of an astronomical geodetic reference point. Radar measurements of the thickness of the ice and aerial magnetic tests were made on Enderby Land. A study was also made of variations in the geomagnetic field using autonomous magnetic variation stations. East German astronomers made a determination of the astronomical points at Vostok and Mirnyy stations. A group of Polish biologists conducted marine biological studies near Molodezhnaya Station.

The program of seasonal work of the 17th Antarctic Expedition also included reconnaissance from the ship Ob' along the coast of Western Antarctica from Cape Colbeck to Cape Dart for the purpose of choosing a place to set up a new Antarctic station.

In addition to scientific research, the expedition had to replace personnel at the Antarctic stations and supply those remaining with the necessary materials, equipment, and food.

The operations to carry out the missions of the expedition were performed with the aid of the diesel electric ship Ob', the diesel electric ship Navarin, the research ship Professor Vize, the motorship Nadezhda Krupskaya, four Il-14 airplanes, two Mi8 helicopters, and four An-2 airplanes.

The seasonal work of the 17th Expedition involved 199 persons of different specializations, 10 of them from East Germany, Bulgaria, Hungary, Poland, and Romania. In addition, associates of the 16th and 17th expeditions who had spent the winter were enlisted for seasonal work.

The Routes of the Ships, Replacement of Station Personnel

The diesel electric ship Ob', commanded by Capt S. I. Volkov, left Leningrad on 9 November 1971 for its 17th Antarctic run. It carried 66 members of the ship's crew and 138 members of the 17th Expedition, including V. G. Aver'yanov, head of the winter expedition. The chief of the run was Ye. S. Korotevich, head of the expedition. The ship carried a load of 142 tons.

During the crossing to the Canary Islands the Ob' adjusted and tuned its echo sounders and satellite apparatus and performed other jobs to prepare for observations en route. Observations of the weather, reception of facisimile picture transmissions and hydrometeorological information, and compiling weather forecasts for the ship's route were begun. Observations of the earth's magnetic field using a towed cesium magnetometor were begun on 16 November as the ship left the English Channel.

The Ob' arrived in the port of Santa Cruz in the Canary Islands on 21 November and, after replenishing supplies of water, fuel, and food, continued its cruise on 23 November. On 29 November the ship crossed the equator, and on 1 December it met at sea with the turbine ship Akademik Shimanskiy, to which mail was transferred.

On 11 December the Ob' entered Antarctic waters and on the same day encountered its first iceberg. On 16 December the ship met the research vessel Professor Vize on the meridian of Moledezhnaya Station at the edge of the pack ice. From it the Ob' took on 129 members of the 17th Expedition and 61 tons of cargo.

On 17 December the Professor Vize set off for Fremantle and the Ob' headed through the pack ice of the Sea of Cosmonauts toward the fast ice near Molodezhnaya Station, where it arrived on 18 December and moored itself at 66° 53' S. and 46° 11' E.

The thickness of the fast ice where the Ob' was moored varied from 92 to 120 centimeters, while the snow was 60-80 centimenters deep and the thickness of the snow-water layer was 40 centimeters. The snow pack on the fast ice was uneven. Bands of snow stretching in a westerly direction alternated with meltwater pools about 50 centimeters deep. Landing zones and runways for the helicopters and An-2 planes were chosen 30-50 meters from the ship. A runway for the Il-14 plane was found one kilometer from the ship in the lee of an iceberg. The ice in this sector was smooth and free of snow. It was 100-200 centimeters thick. The runway was about 800 meters long.

On 19 December a search was conducted for an ice road to transport the Il-14 to the chosen runway. Although the thickness of the fast ice permitted the plane to be carried across it, it was decided to break a channel in the fast ice to the runway because of the uneven snowpack and the many deep meltwater pools, which were dangerous to the plane's skis. The Ob' covered this distance in a few hours. Then the Il-14 was unloaded onto the ice and taken to the assembly point at the runway. On 21 December the plane took off successfully and set its course for Molodezhnaya.

Unloading onto the fast ice and moving freight to shore by airplane and helicopter continued until 24 December, after which the ship set out for Amery Base. The Ob' arrived in the Amery Base region on 30 December. Passing through a belt of pack ice of 4-8 point consolidation, the ship reached the open water before fast ice. An attempt to reach the channel broken earlier by the Navarin to the unloading point failed: the ship became trapped in the channel when the field of fast ice shifted. The next time the ice moved the ship was able, with great difficulty, to get free. With improvement in the ice situation the Ob' approached a floe suitable for a runway and from it the An-2 airplane began delivering people and freight to Amery Base. On 31 December the ship was pushed away from the fast ice and began drifting. On 1 January 1972 it again began unloading at a distance of one kilometer from the runway. By the evening of that day the job was finished; a total of 19 tons of freight had been unloaded as well as part of the group of associates for the seasonal detachments of the 17th Expedition. On the same day the Ob' set off for Mirnyy.

On 4 January during the crossing to Mirnyy the research ship Professor Vize, returning from Fremantle with members of the 17th Expedition who had arrived there by plane, was taken under escort. After safely crossing a belt of pack ice in the Davis Sea, both ships reached the edge of the fast ice near Mirnyy on 6 January.

The first measurements of the fast ice were made near the ships' mooring place. Its thickness ranged from 78 to 131 centimeters, with 50-75 centimeters of snow and a snow-water layer of 22-45 centimeters. On 7 January measurements were made along the entire 35-kilometer ice route from the Ob' to Mirnyy. Two tidal cracks about two meters wide intersected the route near Builders Islands and bridges were laid over them. On 9 January two Khar'kovchanka vehicles and three ATT tractors were driven to Mirnyy. Regular tractor traffic carrying loads began.

On 10 January check measurements of ice thickness were made on the ice road. In three days it decreased an average of five centimeters, but the thickness of the snow-water layer increased the same amount. This allowed us to assume that the ice was thawing from the top down. In the Cape Mabus region the ice thawed 16 centimeters and broke intensively. A large number of meltwater pools up to 0.5 meters deep appeared where the ice thickness decreased to 30 centimeters. Measurements of ice thickness near Cape Mabus on 11 January showed that the top 30 centimeters of the ice had broken up in one day and the bottom layer was very weak. The danger of tractors' breaking through the ice forced a stop in moving cargo to Mirnyy.

New approaches on the fast ice and climbs up the bank had to be looked for on Builders and Tokarev islands. During the night before 13 January the wind picked up and broke the fast ice at the ship's mooring place, causing an An-2 plane and tractor parked on the ice next to the ship to sink. The Ob' drew back from the fast ice and, traveling along the edge of it toward Haswell Island, turned south at 93° 06' E., where ice 40-50 centimeters thick and a broad crack were found in the lee between a cluster of icebergs and Haswell Island. In a few hours the ship traveled about five miles in the fast ice to 66° 31' S., 92° 56' E. From there a new ice road was laid to the Builders Islands. However, no loads were carried along it because a series of wide cracks opened between the ship and the shore on 15 January. The Ob' began breaking a channel through the fast ice to Tokarev Island, which it approached on 16 January. On the same day the Professor Vize and the Navarin arrived there. The most convenient place for transport vehicles carrying loads to climb onto Tokarev Island was a saddle in the southern part. The thickness of the fast ice around the island ranged from 40 to 95 centimeters. It had many meltwater pools beneath which the ice thickness was not more than 30-40 centimeters, so the route chosen was very winding. Two ATT tractors, a caterpillar crane from the Navarin, and part of the cargo of the Ob' were moved onto the island along this road.

On 18 January cargo operations at Mirnyy ended and the Professor Vize and Navarin left. After taking on fresh water from an iceberg standing in shallows near Ploskiy Island, on 19 January the Ob' continued on to Leningradskaya Station carrying 57 members of the 17th Expedition. On 27 January the Ob' reached the edge of the ice in the meridian of Leningradskaya Station. Ice conditions near the station were very difficult. Five attempts were made to break through the 10-point ice toward the station at different points. Only on 13 February did the Ob' reach the fast ice of Leningradskaya Station near Tomilin Glacier and, after breaking a channel about one kilometer long, tied up at the edge of solid, old ice.

The search for an unloading route on the fast ice at Leningradskaya Station began 10 days before the ship approached and was continued when a group of members of the 17th Expedition led by Ye. S. Korotkevich arrived at the station from the Ob' by airplane. Many cracks were found in the fast ice near the station, and the snow-water layer was particularly large. Attempts to find a suitable place to lift the cargo up onto the barrier and for a safe unloading route were unsuccessful for some time. A place to bring the cargo up was found 10 kilometers west of the station, called Pod"yem point. At this point the ice barrier for 100-150 meters had a height of 2-2.5 meters and the inclination of the ice surface was 15-20 degrees. A road 13 kilometers long was selected after examination of the fast ice. The thickness of the snowpack on it was 200-300 centimeters and the ice was 150-250 centimeters thick. The most dangerous cracks were no more than three meters wide. Bridges were laid across these cracks. A swamp tractor sank on 13 February during the laying of one of these bridges.

On 18 February the first tractor pulling a load covered the road. In the region of the ice barrier the load was lifted onto the ice by a bridge thrown from the fast ice to the barrier. A long line was stretched to the fast ice from a tractor situated on the shelf. Light sleds carrying about three tons of cargo were secured to the line and then towed onto the shelf (see Figure 2). Most of the cargo was moved over in this way. From this point it was hauled to the station by a route laid out on the ice. The cargo was hauled across the fast ice by GTT all-terrain vehicles towing light sleds.

The unloading work had to be done in difficult weather. The fast ice cracked on 24 February and the route was no longer suitable for moving cargo. Therefore, the last two days of unloading were done at a new place using only GTT vehicles. The vehicles crossed a wide crack on the route over a snowdrift near an iceberg. Part of the cargo was moved by the An-2 plane commanded by Yu. P. Matyatin and K. V. Karagodin.

Unloading work at Leningradskaya Station was finished on 26 February and the Ob' left for the coast of Marie Byrd Land in Western Antarctica in order to choose a site for setting up the new Russkaya Station. The ship was carrying 29 members of the 16th and 17th expeditions and 354 tons of cargo.

Reconnaissance to choose the site of the Russkaya Station. The Ob' arrived in the Cape Colbeck region (Ross Sea) on 29 February and began exploring the coast of Marie Byrd Land in an easterly direction.

The ice situation in this region took shape as follows. A belt of consolidated ice 145-360 kilometers wide was located along the coastal sector between Cape Colbeck and the Thurston Peninsula in January with its southern boundary running 100-145 kilometers from the shore. An enormous area of open water was observed from the southern edge of the ice to the shore. By mid-February the ice had moved to the shore in the segment of coast between Cape Colbeck and 140° W, and by the end of the month only a narrow, discontinuous strip of open water remained there. East of 140° W there were no significant changes in the ice situation. The Ob' reached Berkes Cape on 4 March and tied up at the edge of the old fast ice.

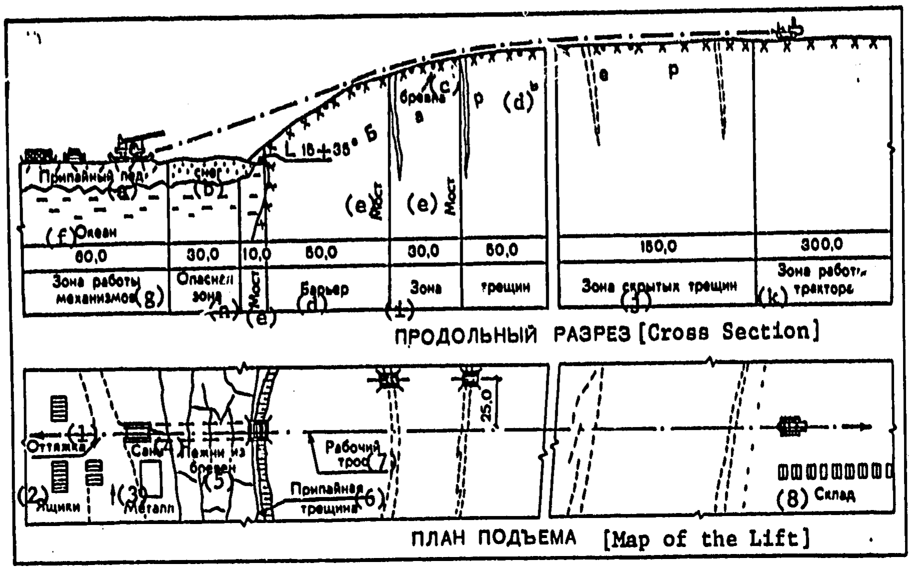



Figure 2. Diagram of Lifting Cargo onto the Barrier near Leningradskaya Station

Key:
(a) Fast Ice;
(b) Snow;
(c) Logs;
(d) Barrier;
(e) Bridge;
(f) Ocean
(g) Zone of Machine Work;
(h) Danger Zone;
(i) Crack Zone;
(j) Concealed Crack Zone
(k) Zone of Tractor Work;
(1) Guy Rope;
(2) Boxes;
(3) Metal;
(4) Sleds;
(5) Ramp of Logs;
(6) Crack at Edge of Fast Ice;
(7) Working Line;
(8) Storehouse.

Between 1 and 5 March the forward part of a cyclone passed over the Cape Colbeck-Cape Dart region. The weather was cloudy with some clearing and no significant precipitation. The wind blew at up to 10 points and the air temperature ranged from 0 to -4 degrees. Then the Antarctic continental and subtropical anticyclones grew stronger. The latter occupied the entire southern part of the Pacific Ocean. Deep cyclones with trajectories passing between 60-65° S. raced into the low-pressure corridor between these anticyclones. Their speed of travel was about 50 kilometers an hour. All these conditions led to heavy snowfall and east winds of up to 35 meters a second in the ship's cruising region. The depth of the cyclones decreased on 8-14 March and their trajectory shifted to the north, but the east winds at 20-25 meters an hour and snow storms continued.

During the night before 5 March the Ob' rounded a protrusion of fast ice from the north, examining the northwestern approaches to Berkes Cape and the coast to Shepard Island. The wind reached 40 meters a second; a blizzard began and continued, with short breaks, until 11 March.

The ship approached Shepard Island in the evening with good visibility and a strong wind. An attempt to reach shore at a point where the ice barrier was not so high failed because of shallow depths. The lack of fast ice around the island made it impossible to unload the airplane or surface transport. The ship set off for Cape Dart, which it reached in a hurricane wind exceeding 40 meters a second and poor visibility. The only possible place to locate the station, Lauville Cliff, was examined from the water. It was determined that building the station there would be inadvisable. From this point the Ob' again set off for Berkes Cape.

Examination of the coast between Berkes Cape and Cape Dart showed that the shoreline in this sector is an ice precipice 10-40 meters high. The shore is ringed by old fast ice 20-30 kilometers wide and 3-4 meters thick from Krusen Island to Berkes Cape. Rock outcroppings were found along the coast on Krusen Island, at Berkes Cape, on Sheperd Island, and at Lauville Cliff at Cape Dart. On Krusen Island the rock outcroppings are steep precipices covered on top with ice and snow. The Lauville Cliff is a group of steeply sloped walls 50-100 meters high. Shepard Island has a number of outcroppings of bedrock in steep precipices and jagged summits. There are two flat sectors, one of them a low terrace 200 meters long at the bottom of a mountain slope and the second Matthewson Cape, where the bedrock outcroppings are a series of terraces 20-30 meters high rising to a summit of 150-200 meters. The total length of this denuded surface from the shore to the summit is about three kilometers. Only the lower two terraces have level platforms. The first terrace drops off straight into the sea.

Berkes Cape is a rocky region of low hills that rises in a fairly gentle slope from the water to an altitude of about 200 meters. There are numerous level areas. Two extended lines of hills and a series of individual summits stand out (see Figure 3). On the northwest the cape is bounded by fast ice 20-30 kilometers wide. Owing to movement of adjacent shelf ice the fast ice has many cracks of different widths.

The examination indicated that Berkes Cape is the most suitable place for construction of the station.

On 12 March reconnaissance work on the coast of Marie Byrd Land was completed and the Ob' set its course for Littleton. On 13 March the ship was caught in new floes compressed by strong winds. It became stuck several times. The ice around the ship had to be broken manually or with explosions. On 18 March the weather situation changed abruptly, the ice broke up, and the Ob' escaped to a belt of pack ice. On 20 March the ship reached open water and set out for Littleton, where it stayed from 29 March to 2 April. Supplies of fuel, water, and food were

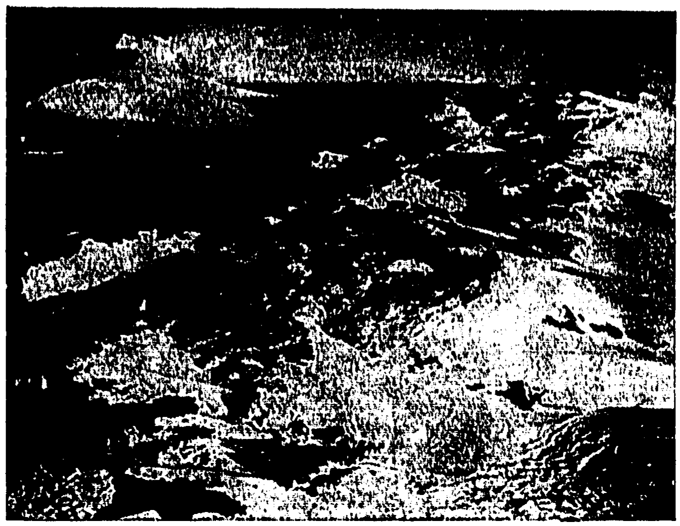


Figure 3. Berkes Cape (view from the northwest)

replenished in Littleton and then the ship returned again to Leningradskaya Station to supply it with fuel and fresh food and pick up the personnel of the 16th Expedition. In this crossing the marine detachment performed a hydrologic section from 19 deep-water stations. On 5 April the ship met the fishing trawler Danko at sea and passed mail to it.

On 13 April the Ob' reached Leningradskaya Station and tied up at the edge of the ice at Pod"yem Point. Unloading work began. The wind picked up on 14 April, the mooring lines broke, and the ship began to drift. On 15 April the wind let up and the ship again tied up and began unloading. On 17 April a blizzard began with gusts of wind up to 35-40 meters a second. The mooring lines broke and the ship again began drifting. The fast ice east of the station cracked and the strong wind carried fields and fragments of it west along the shore. The Ob' was forced against the Tomilin Ice Shelf 10 kilometers from Pod"yem Point and trapped. Attempts to break through to the barrier failed and so further unloading was done entirely by the An-2 plane, while some of the building materials had to be unloaded onto the old fast ice. The plane's last cargo run was made on 26 April. In all 164.5 tons of cargo was delivered to the station. On 30 April the Ob' departed from the thick fast ice and entered a zone of young pack ice. After this it reached open water and set course for Mirnyy Station, carrying 48 members of the 16th and 17th Expeditions.

On 8 May the Ob' reached the edge of the pack ice near Mirnyy Station (62° 48' S. and 95° 39' E.). The ice consolidation in this region reached 10 points. It was not possible to find a passage through the ice and aerial reconnaissance of the ice produced no results either. The approach to the barrier was closed. On 10 May a shelf was found 220 kilometers from the station. It was 300 meters long by 150 meters wide and eight meters thick. On the same day the first flight by the An-2 plane to Mirnyy was carried out. During 11 and 12 May four more flights were made. The Ob' took on 38 members of the 16th Expedition from Mirnyy and about two tons of cargo, including material from scientific observations. It delivered food to the station. On 12 May the Ob' set its course for Molodezhnaya Station, carrying 85 members of the 16th Expedition and the seasonal group of the 17th Expedition.

The Ob' arrived in the Molodezhnaya region on 19 May. The ice situation there was difficult. Aerial ice reconnaissance by the Il-14 plane based at the station, commanded by I. V. Cheremukhin and carrying hydrologist V. D. Klokov, was begun even before the ship approached. Nine reconnaissance missions were flown between 15 and 29 May. The Ob' came through heavy ice with difficulty, making use of the findings of these missions. It was impossible to get close to the station. On 29 May the plane found a mesa-like iceberg in a zone of 10-point ice at 66° 09' S. and 48° 18' E. A site for a runway was selected there. The runway was 215 kilometers from Molodezhnaya. The cargo began to be unloaded onto the iceberg that same day and flights to Molodezhnaya were begun, continuing until 1 June. Food was shipped to the station and the Ob' received back scientific materials, equipment, and 27 members of the expedition. On 1 June the Ob' with 111 members of the expedition on board set off for the Motherland.

The ship spent 24-26 June in port at Santa Cruz. On 5 July it put two German scientists ashore at Warnemund. The ship arrived in Leningrad on 7 July 1972. Its cruise to Antarctica had lasted 242 days.

The diesel electric ship Navarin, commanded by Capt Yu. K Karlov (now deceased), set off on its first Antarctic voyage on 6 November 1971. On board were the 58 members of the ship's crew, 21 associates of the 17th Expedition, and 2,092 tons of cargo. The chief of the run was D. S. Solov'yev, deputy chief of the 17th Expedition in charge of seasonal work. The ship reached Las Palmas on 16 November. After replenishing its supplies of fuel, water, and food it continued the voyage on 17 November. On 15 December the Navarin reached the edge of the fast ice of Sandefjord Bay near the Amery Ice Shelf, where the Amery base was to be set up. Supplying this base was the ship's primary objective in Antarctica.

Ice exploration had to be carried out to determine the nature of the fast ice and find a place suitable for unloading and setting up a runway for the planes. A temporary runway was marked out 300 meters from the ship, cut into the fast ice 700 meters from its edge. The fast ice had an average ice thickness of 165 centimeters, with 35-40 centimeters of snow and a 15-20 centimeter snow-water layer. Three ice reconnaissance flights were made in an An-2 on 17-18 December, examining the waters of Sandefjord

Bay, the northern part of the Proclamation Glacier, and the northeastern boundary of the Amery Ice Shelf. A site for the Amery base and an airstrip was found in the southwestern part of the bay at the point with coordinates 69° 43.22' S. and 73° 43.49' E. Reconnaissance findings indicated that the fast ice closes in the entire southwestern shore of Prydz Bay. The fast ice is 20-25 kilometers wide with hummockiness of four points in the central and northeastern parts of Sandefjord Bay and snow encrustation of three points over its entire area. The route from the ship to the shore base crossed seven cracks, six of them 4-6 meters wide and one 10-20 meters in width. The first crack was seven kilometers from shore and 14 kilometers from the ship. The cracks narrowed to 2-3 meters along the western shore of the bay (barrier of the Amery Ice Shelf). On the north the fast ice was ringed by a narrow (500-1,000 meters) polynia. A zone of eight-point pack ice 8-10 kilometers wide and the open water of the polynia near the shelf stretched further to the northeast. A block of 9-10 point pack ice was located along the barrier of the Amery Ice Shelf and northeast of it.

With such a fast ice situation it was not possible to unload using ground transportation. To begin work the ship would have had to break through the fast ice at least to the first crack, which was some 15 kilometers, and this would have taken a great deal of time. It was decided to break through to a level sector of fast ice and begin unloading by airplane. The Navarin broke its way to such a sector between 18 and 30 December, traveling just eight kilometers in all. At first the ship moved 500-700 meters a day. Its advance was hindered by the great thickness of the fast ice (165 centimeters), the large amount of snow, and especially the hummocks. The ship became wedged in more than once. It was trapped for 2.5 days on 20-22 December and for 1.5 days on 27-28 December. It was stuck for several hours on other days.

After crossing the wide crack the number of hummocks decreased greatly. The ship covered about three kilometers in a day. Measurements made on the ship-to-shore line indicated that the thickness of the fast ice in profile averaged 150 centimeters and the snow-water layer was 40-50 centimeters. Because of the wide cracks unloading on the fast ice could not be organized. Only the tractor, bulldozer, and all-terrain vehicle were carried in. The relatively level surface of the ice where the ship was located allowed the aircraft to land and take off. On 30 December unloadifig was begun by means of An-2 airplanes and Mi-8 helicopters. It was completed on 10 January. A total of 993 tons was unloaded. On the same day the Navarin set out for Mirnyy.

The Navarin arrived at Mirnyy on 16 January. The ship was unloaded at Tokarev Island. On 18 January, leading the research vessel Professor Vize, the Navarin left Mirnyy. After piloting the Professor Zubov [sic], the Navarin set course for the port of Punta Arenas, Chile, to replenish its supplies of fuel, water, and food. The ship was in port at Punta Arenas from 4 until 10 February.

The Navarin arrived at Bellingshausen Station on 13 February, and unloaded until 19 February. During this time 260 tons of various cargo and 95 tons of diesel fuel was transferred to the station. On 19 February the ship set out for Molodezhnaya Station. On 29 February in Alasheyev Bay the Navarin took the Nadezhda Krupskaya in pilotage. Both ships approached the fast ice of Molodezhnaya Station on 29 February. On 1 March the Navarin began breaking a channel in the ice, which was 30-60 centimeters thick. After a channel had been broken to a place suitable for setting up a runway, the Nadezhda Krupskaya drew up, and airplanes began unloading it while diesel fuel and water was pumped from the ship to the Navarin.

On 6 March, after it was unloaded, the Nadezhda Krupskaya was piloted to open water by the Navarin, which returned to Molodezhnaya on 7 March and tied up at the pier on the shelf barrier. Cargo was unloaded onto the barrier, with considerable interruptions caused by stormy weather, until 19 March. A total of 809 tons was unloaded. The ship took on two Mi-8 helicopters, an Il-14 airplane, and fuel and water. On 21 March the Navarin left Molodezhnaya and set sail for Novolazarevskaya Station.

It arrived in Leningrad Bay on 25 March. Reaching the edge of the fast ice, the ship began breaking a path to Lazarev Station. The ice was snow-encrusted; its thickness was 50 centimeters. Movement through the fast ice was very slow because of the ship's ballast condition. By 27 March the ship had moved about two kilometers through it. The ice thickness increased to one meter. On 28 March the Hurricane Cape region was investigated. On 1 April a sled and tractor train from Novolazarevskaya reached the side of the ship and unloading began. It was completed on 3 April. Fifty tons of diesel fuel and 83 tons of food and equipment was transferred to the station. The ship set its course for Bellingshausen Station, carrying 21 members of the Antarctic expedition.

The Navarin reached Bellingshausen Station for the second time on 14 April and, taking on five more associates of the expedition, set off the same day for the Motherland carrying 26 participants in the 16th Expedition. The ship stopped at Montevideo on 20 April for water and fuel. Atfer a stop in Santa Cruz on 10 May to replenish supplies of water and fuel, the Navarin sailed for Leningrad and arrived on 22 May 1972.

The voyage of the research vessel Professor Vize. The Professor Vize, commanded by Capt E. N. Troitskiy, left Leningrad on 9 November 1971. It was carrying 136 members of the 17th Expedition (10 of them non-Soviet scientists) and about 100 tons of cargo. The ship had a crew of 109 persons. The chief of the voyage was A. N. Chilingarov. They stopped at the port of Gdansk on 14 November to pick up five Polish specialists taking part in the 17th Expedition. The ship was in port at Las Palmas from 22 to 25 November to replenish supplies of food and fuel. During the crossing from Las Palmas to Molodezhnaya Station the ship made a hydrological section from Cape Agulhas to the Prince Edward Islands.

On 16 December the Professor Vize met the diesel electric ship Ob' at the edge of the pack ice of the Sea of Cosmonauts. It transferred 129 members of the 17th Expedition and 61 tons of cargo to the Ob' and set off for Fremantle on 17 December. This crossing took nine days. Between 26 and 28 December 61 associates of the 17th Expedition, who had arrived from the USSR by scheduled airliner, were taken on board ship in the port of Fremantle. The Professor Vize left for Mirnyy on 28 December.

The Ob' began piloting the ship on 4 January 1972 at the northern edge of the ice of the Davis Sea. Crossing the pack ice zone, both ships reached the edge of the Mirnyy fast ice on 6 January. The Professor Vize completed cargo operations at Mirnyy on 18 January, took on board associates of the 16th Expedition, and set its course for the Motherland. During the crossing from Antarctica to Africa at 20° E. a hydrological section of 20 stations was made from the ship. The Professor Vize arrived in Santa Cruz on 15 February and left again on 18 February, after replenishing supplies of water and fuel. The ship arrived in Leningrad on 26 February.

The voyage of the motorship Nadezhda Krupskaya. The Nadezhda Krupskaya, commanded by Capt A. A. Aristov, left Leningrad on 22 January 1972 with a crew of 103 and carrying 49 members of the 17th Expedition, scientific equipment, and food. On 31 January-1 February the ship stopped in the port of Laz Palmas to stock up on fuel and food and receive on board an American microbiologist. The ship stopped at the port of Abidjan on 6-7 February and then set its course for Molodezhnaya.

It proved impossible to get close to Molodezhnaya Station because of poor ice conditions, so the ship went directly to the Amery base, arriving on 23 February. Sandefjord Bay was completely free of ice and the ship was able to reach the shelf barrier. There were difficulties in approaching the barrier because this was the first time a Soviet ship had sailed these waters and it had no navigation charts. After taking on 49 members of the seasonal detachment of the expedition and 25 tons of cargo, the motorship left Molodezhnaya on 25 February, carrying 98 participants in the 17th Expedition.

The Nadezhda Krupskaya met the diesel electric ship Navarin at the edge of the pack ice in the Sea of Cosmonauts on 28 February and, piloted by the Navarin, approached the fast ice of Molodezhnaya Station on 29 February.

Cargo operations at Molodezhnaya went on from 2 to 6 March. On that day the motorship, piloted by the Navarin to open water, left Molodezhnaya and set sail for the Motherland, carrying 172 members of the 16th and 17th Expeditions. Three stops at foreign ports were made on the return trip: 20-21 March at Abidjan, 26-28 March at Las Palmas, and 3 April at Gdynia. The five Polish scientists who took part in the seasonal work of the 17th Expedition were landed at Gdynia. The Nadezhda Krupskaya reached the Motherland at Kaliningrad on 4 April.

The flight from Moscow to Australia. At 2105 of 26 December an Il-62 airplane left Moscow carrying 61 members of the expedition, led by V. A. Anan'yev, head of Vostok Station. The plane made landings in Bombay, Colombo, Kuala Lumpur, and Singapore.

On 27 December in Singapore the members of the group changed to a Malaysian Air Boeing 707 and flew to Perth. From Perth they were taken by bus to the research ship Professor Vize in Fremantle. The ship set out for Antarctica. The entire flight from Moscow through Singapore to Perth took from 2105 of 26 December until 1950 of 27 December, that is 22 hours and 45 minutes.

The Organization of the Amery Base

A comprehensive study of Eastern Antarctica (68-76° S. and 61-75° E.) was begun in the Antarctic summer of 1971-72. This is a region of mountains and glaciers with a total of 300,000 square kilometers. It encompasses a large part of Mac-Robertson Coast, including the Prince Charles Mountains, Lambert Glacier, and Amery Ice Shelf as well as the western part of Princess Elizabeth Coast. This work was figured for several years. The need for research came chiefly from the extremely low level of study done on this region, even though there was already information on the presence there of extremely interesting (even unique) characteristics of geological structure, glacial geomorphological features, and manifestations of useful minerals.

This region is one of the few in Eastern Antarctica where outcroppings of bedrock are not localized in a comparatively narrow coastal zone, but rather strike south into the depth of the continent more than 700 kilometers, which makes it possible to formulate a direct picture of the geological structure of the internal provinces of Eastern Antarctica which are solidly covered by ice elsewhere. Another important factor favoring serious field investigations in this region was the discovery of a Proterozoic iron ore formation in the Cooperation (Sodruzhestva) Mountains by members of the 11th Expedition and a Permian coal formation near Beaver Lake by Australian geologists. It had become vitally necessary to get thorough information on these geological objects in connection with drawing the summary geological map on a scale of 1:5,000,000.

At the beginning of investigation most of the region had been covered only by preliminary surveying done by the Australian expedition chiefly along the routes of tractor and sled parties and by the Soviet Antarctic Expedition using a widely spaced net of aerial geophysical and geological routes. No aerial photographic surveying by area had been done, so cartographic materials were not precise.

The plan of work and support for it. The inaccessibility of the study region and its remoteness from the Soviet Antarctic stations (1,400 kilometers from Molodezhnaya and about 1,000 kilometers from Mirnyy) required a significant concentration of men and equipment in order to carry out a broad program of scientific investigations in a very short time period.

For this reason the plan of work included not just geological and geophysical studies of various scales but also study of the relief of the bedrock floor beneath the ice, topographical-geodetic and aerial surveying work, geographic landscape and biological observations, and solving a number of methodological problems of using various kinds of geophysical and radio geodetic equipment in Antarctic conditions, primarily for geological and geomorphological mapping beneath the ice.

The geological studies envisioned consideration of the sections, the character of the bedding and structural position of the Upper Proterozoic green shale beds in the Cooperation Mountains and precise determination of their age; sections of the Upper Paleozoic sedimentary strata and the extent of their saturation with coal in the Beaver Lake region; preliminary areal surveying of the metamorphic and intrusive complexes of the crystalline basement throughout the region and identification of the nature of the distribution of various metamorphic facies. Study of manifestations of useful minerals and preliminary assessment of them was mandatory for all sections of the geological program.

The plan of geophysical studies included comprehensive geophysical surveying by air landing on a scale of 1:3,000,000 (gravimetric and absolute magnetic measurements, seismic sounding by the reflected wave technique, and barometric and astronomical observations) over an area of 100,000 square kilometers and aerial magnetic surveying on a scale of 1:2,000,000 for an area of 280,000 square kilometers.

The topographic geodetic studies envisioned aerial surveying of 60,000 square kilometers on a scale of 1:68,000.

The geographic landscape studies envisaged glacial geomorphological mapping of an area of 100,000 square kilometers, study of unconsolidated deposits and the processes of glaciation, and biological observations.

The plan for experimental methods work involved development of methodology and practical implementation of an autonomous Doppler radio geodetic system in practical aerial surveying and transport flights under Antarctic conditions; development of techniques and practical implementation in aerial surveying flights of simultaneous aerial magnetic surveying and radar sounding of the thickness of the ice cap with a radio geodetic system and aerial photography equipment; investigation of the possibility of using the medium wave variant of the radio geodetic system for air landing geophysical studies on Antarctic glaciers.

The principal organizational problem was to set up the Amery base camp on the coast of Prydz Bay, which required unloading about 1,000 tons of various items of cargo of different sizes and fuel and lubricants from the ship at an appropriate place. Then, supported by this base camp, eight field camps were to be set up at distances of 250-600 kilometers away from it. These very broad scientific and organizational objectives were to be met in one field season. It was the first time the Soviet expedition had untaken such a large task.

The Amery group which was to carry out this vast program of field work had more than 100 scientific-technical personnel grouped into the geological-geophysical detachment (23 members headed by G. E. Grikurov), the topographical-geodetic detachment (18, headed by G. M. Muradov), aviation group (51 members, headed by P. P. Moskalenko), the hydrobiological group (3 persons, led by Ye. N. Gruzov, 16th Expedition), the base services group (seven persons), and the Bulgarian writer S. G Karaslavov. The base services group was formed from the overwintering groups of the 16th and 17th expeditions and scientific methods guidance for the projects was provided by D. S. Solov'yev (now deceased), deputy chief of the 17th Expedition in charge of seasonal work.

The Amery group was assigned two Mi-8 helicopters (crew commanders B. A. Steblenko and L. N. Anton'yev), two An-2 airplanes (crew commanders V. M. Karpenkov and N. P. Karabanov), and two Il-14 airplanes (crew commanders I. A. Sokolov and V. I. Cheremukhin) for the entire field season to provide transport support to the studies. The Il-14's were equipped for aerial magnetic and photographic surveying. For land transport the Amery camp had a tractor, a bulldozer, and a GTT all-terrain vehicle.

Primary stages of field work. Maps of the coastal region in Sandefjord Bay where the landing was planned were available. They were based on 1956-1957 findings. It was known that the configuration of the ice shores had undergone major changes in subsequent years in connection with the breaking off of enormous pieces of the Amery Ice Shelf, the northern part of the Polar Record Ice Shelf, and the tongue of the Polar Times outlet glacier. This made it much harder to find a site for the Amery camp.

The site for the camp had to be suitable for ocean-going ships to approach and unload at the start and end of the Antarctic summer but at the same time be guaranteed against the danger of ice breaking off in the coastal zone during strong winds. In addition a reliable airfield as close as possible to the regions of field work was needed for various types of aviation.

The Navarin arrived in Sandefjord Bay on 15 December. Aviation reconnaissance indicated that the entire water surface of the bay between the Amery and Polar Record ice shelves was covered by fast ice 5-30 kilometers wide. A narrow fast ice zone was located near the northern edge of the shelves, but the height (15-60 meters) and steepness (90 degrees) of the barrier precluded unloading from the seaward side. The coastal zone of these ice shelves, 10 kilometers wide, was dissected by many cracks and thus was not suitable for setting up airfields and presented a danger in the case of calving icebergs. The ice sectors of the shelf slope on the southern shore of the bay were also unsuitable for a camp because of the ruggedness of the relief and fractured character of the ice cover.

The most suitable site for setting up the base camp was judged to be the sector of the Amery Ice Shelf located between two nunataks in the southwestern back part of Sandefjord Bay (69° 43' 22" S., 73° 43' 49" E.) This sector met almost all requirements: good approaches to the barrier from the fast ice; a barrier height (2-6 meters) and water depth that allowed ships to draw close and unload directly onto the barrier; a shelf surface in suitable condition for setting up several runways for ski planes; coastal nunataks that provided some degree of protection against large break-ups of the shelf.

The first KAPSh-2 tent was pitched at the chosen site on 18 December. Three An-2 planes began unloading the Navarin during the night before 30 December.

On 1 January 1972 all the personnel of the geological-geophysical and topographic-geodetic detachments plus four An-2's and one Il-14 were already based at Amery camp. They were joined the next day by two Mi-8 helicopters which then took care of unloading fuel and lubricants from the Navarin. Eleven KAPSh-1 and KAPSh-2 tents were pitched in the camp and 14 PDKO huts were set up, including a double hut to be used as a dining hall. The radio station was set up, a runway marked off, and the general cargo stored (see Figure 4 below). On 5 January a group of expedition members led by A. N. Chilingarov, crossing dangerous cracks, brought a bulldozer, GTT all-terrain vehicle, and tractor over the ice to the camp.

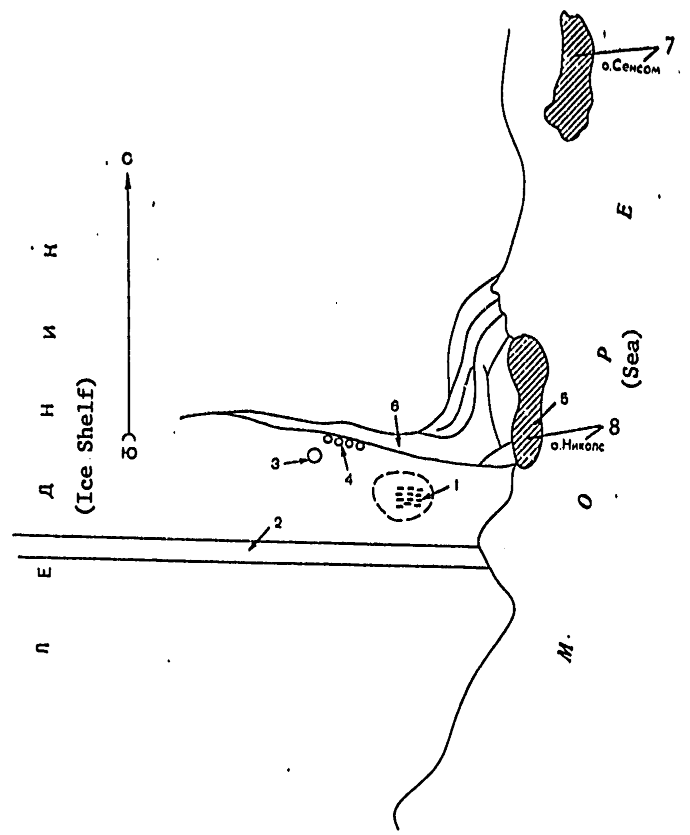



Figure 4. Amery Camp.

Key: (1) Huts;
(2) Runway;
(3) Fuel and Lubricant Storage;
(4) Empty Barrels;
(5) Bedrock Outcropping;
(6) Cracks;
(7) Sansome Island;
(8) Nikops Island.

Between 4 and 10 January, while the unloading of fuel and lubricants and construction of the camp was being completed, reconnaissance flights were made into the mountains and the field geological camps, barometric posts, and long-range radio stations began to be set up. In this same period, on 7 January, the camp at Beaver Lake began functioning with its continuously operating barometric post, magnetic variation station, and geological group, whose job included compiling a detailed section of the Permian deposits and studying the geomorphology and glacial processes in the Jetty Oasis. At almost the same time a portable barometric post was set up on the Grove nunataks (72° 42' S., 74° 25' E.), making it possible to begin a comprehensive geophysical survey of the eastern part of the region by air landings. At this time too the Il-14 plane flew photo framework routes for a subsequent aerial magnetic survey.

On 11 January helicopters were used to deploy two long-range radio stations: RDS-1 on Riddell Nunatak (69° 54' S., 63° 49' E.) and RDS-2 on an ice dome (71° 21' S., 63° 48' E.). An aerial photography Il-14 plane arrived for permanent basing at Amery Camp the same day and an An-2 was re-equipped for comprehensive geophysical ground surveying.

On 12 January all the detachments and groups began carrying out their scientific programs. G. E. Grikurov's geological group was the exception. Their work had to wait for establishment of a field camp in the Cooperation Mountains, roughly 600 kilometers south of Amery Camp. Only on 19 January was this camp set up on Mount Rubin (73° 26' S., 65° 05' E.).

On 31 January the portable barometric post was relocated from the Grove nunataks to the coast near Cape Darnley (68° 30' E., 67° 58' S.), which made it possible in February to shift the focus of the air landing geophysical survey to the northwestern and western parts of the region. The bulk of the aerial landing reconnaissance geological, geomorphological, and biological work over most of the region, done on specialized geological air routes and during air landing geophysical surveying, also fell in the first half of February. Visual air observations of geomorphology were made throughout the season on most airplane and helicopter missions and also on ground routes from both geological field camps.

On February 7, after completing half of the aerial photographic survey, RDS-1 was moved to the summit of Mount Creswell (72° 44' S., 63° 47' E.); the field base of the Australian Antarctic Expedition was located at the foot of the mountain. The geological camp in the Cooperation Mountains was shut down the same day and three days later a new field camp was set up on Lake Radok, 15 kilometers from the earlier camp on Beaver Lake. Just two people stayed at Beaver Lake to insure operation of the continuous barometric post and the magnetic variation station. Most of the members of the geological-geophysical detachment were concentrated at the new geological camp. Through their joint efforts a layered section of the platform deposits was drawn and geomorphological and biological observations were made at Jetty Oasis.

The geological, geomorphological, and biological studies at the field camps were completed on 16 February. The scientists returned to the Amery base camp. From there they continued making one-day flights to different points in the region until 20 February. The group of skindiving hydrobiologists arrived at Amery Camp from Mirnyy on 16 February. They had made a series of dives to study underwater organisms in Sandefjord Bay. On 19 February expedition members flew to the Australian station at Mawson in order to transmit the absolute value of gravity to Amery from there.

Field geological and geophysical work was completely finished on 20 February, ending with the closing of the portable barometric posts at Beaver and Darnley and the return of all detachment members to Amery Camp. The next day RDS-2 was dismantled and RDS-3 on Mount Creswell was put in storage for work in the following year. The personnel of the Amery group began closing down the base camp for the season. Because the Navarin was caught in the roadstead at Bellingshausen Station, the Nadezhda Krupskaya was assigned to remove personnel from the camp.

On 23 February the airplanes and helicopters flew to Molodezhnaya, taking a large part of the topographic-geodetic detachment with them. The Nadezhda Krupskaya approached Amery Camp that same day, but was forced to withdraw to the outer roads because of a strong shoreward wind and the lack of depth soundings in the bay. On 25 February the ship tied up at a prepared ice pier and the camp was evacuated in five hours.

Organization and Conduct of the Glaciological Expedition

In accordance with the International Antarctic Glaciological Project, the 17th Expedition carried out the first stage in the expedition along the route from Mirnyy to Vostok, a trip figured for several years. The primary objective of work in 1971-1972 was to organize the caterpillar-sled train, test the equipment, and develop the methodology for comprehensive studies of the ice cover.

During the expedition scientists made magnetic observations, did radar and seismic sounding of the ice cover, drilled wells to take core samples, measured heat in wells, compiled stratigraphic descriptions of the cores taken from wells and bore pits, made snow measurements, and performed geochemical tests and meteorological observations with barometric leveling.

Studies were made along the entire 171-kilometer route of the expedition and at two testing sites (see Figure 5, next page). The expedition was headed by A. N. Lebedev, chief of the transport detachment of the 16th Expedition.

The personnel of the train were:

| | |
|---|---|
| V. A. Kazarin | deputy expedition leader, engineer and magnetologist (16th Expedition) |
| V. S. Pozdeyev | chief of the seismic sounding group, geophysicist |
| V. B. Golubentsev | drilling and blasting engineer |
| O. L. Levandovskiy | senior radio technician, navigator of the |

| | |
|---|---|
| | expedition (16th Exp.) |
| A. M. Shalygin | junior research associate, physicist |
| L. A. Fedorinchik | radar engineer |
| V. F. Fisenko | senior research associate (drilling) |
| N. Ye. Bobin | senior engineer (drilling) |
| V. D. Utyanov | senior electrical engineer (16th Exp.) |
| V. V. Vysochkin | chief, geochemistry detachment |
| V. K. Kandybarov | senior engineer, geochemist |
| I. F. Khmelevskoy | junior research associate, glaciologist |
| A. N. Doronin | geochemist (16th Exp.) |
| Yu. A. Chelnokov | mechanic-driver (16th Exp.) |
| B. S. Yevseyev | " " |
| V. Ye. Kharlamov | " " |
| Ye. N. Nikanorov | doctor-cook (16th Exp.) |

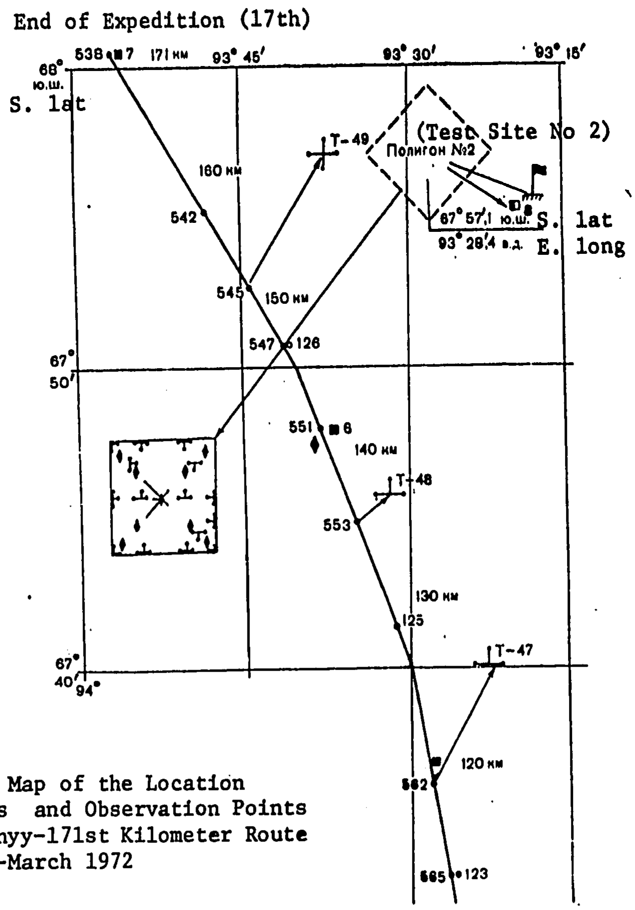
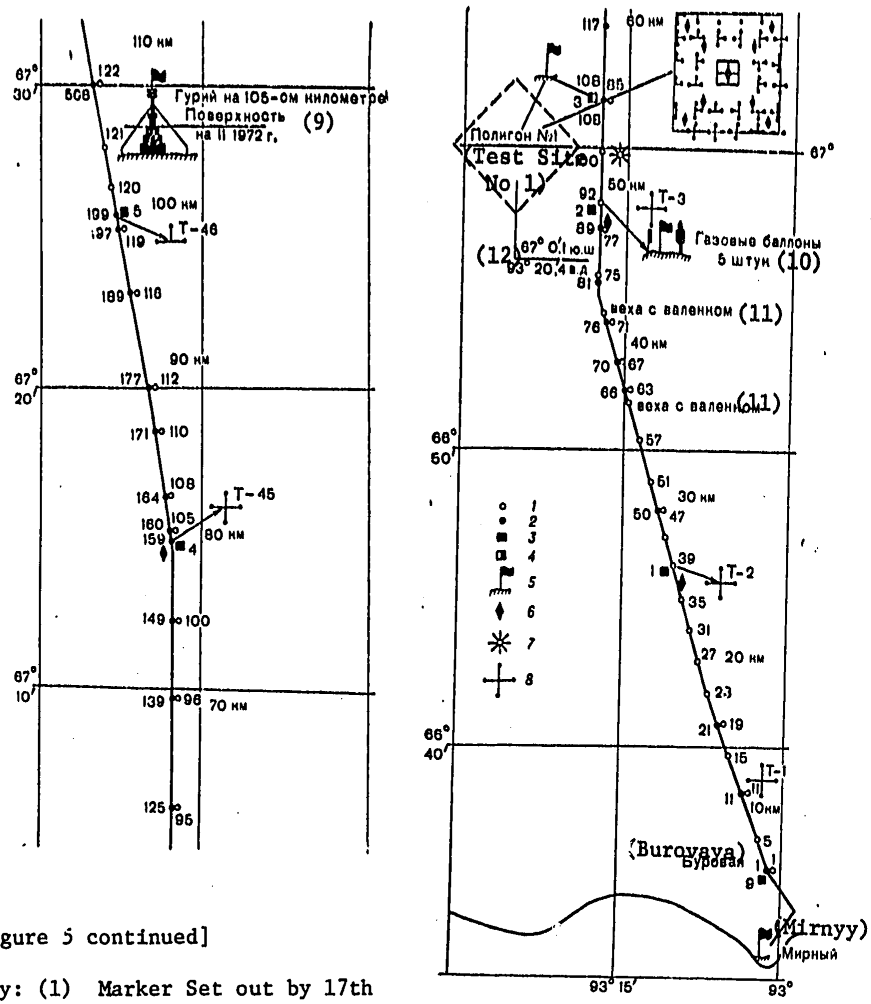



Figure 5. Map of the Location of Markers and Observation Points on the Mirnyy-171st Kilometer Route in January-March 1972



[Figure continued, key, next page]




[Figure 5 continued]

Key:
(1) Marker Set out by 17th Expedition;
(2) Markers Set out Before 17th Expedition;
(3) Glaciological Bore Pits;
(4) Magnetic and Glaciological Bore Pits;
(5) Well;
(6) Magnetic Observation Points;
(7) Presumed Center of Crack Formation;
(8) Seismic Sounding Points;
(9) "Guriy" at Kilometer 105, [Line indicates] Surface in February 1972;
(10) Five Gas Canisters;
(11) Markers with Felt Boots;
(12) 67° 01' S., 93° 20.4 E.

Two STT Khar'kovchanka tractors, an ATT, and three sleds with living quarters and a drilling shed mounted on them were used in the trip.

The personnel of the train, 18 persons, were arranged as follows: five in the STT-21, four in the STT-23, two in the galley hut, three in the drilling shed, and four in the living quarters.

The entire route was covered in 55 days, from 27 January to 21 March 1972. It took eleven days to study test site No 1 (6-17 February 1972) and 19 days at site No 2 (28 February - 18 March 1972). In addition, thermal measurements and seismic logging were done at the well located at kilometer No 49 (the well was drilled by the 14th Expedition). The expedition took place in strong winds, low temperatures, and poor visibility.

The first vehicle to start off was the STT-21, pulling the sleds with the galley hut and living quarters. The work plan for the personnel of this vehicle included finding the mileposts and taking snow samples for geochemical analysis. The second vehicle was the STT-23; radar soundings of the ice were made from it and readings taken every 250 meters. The ATT-52 towed the sleds carrying the drilling shed. The ATT-52 and STT-21 alternated in the jobs of measuring and setting out snow gauges and taking readings of snow density.

Some 15-20 kilometers before reaching the place chosen for the test site the STT-23 moved out in front to find, by radar sounding, places with 100-300 meter drops in under-ice relief. After this the train moved to the center of the sector that was suitable for a site. The drilling shed was set up there and well drilling began. The STT-21 and STT-23 used directional gyros and regular speedometers to mark off a square five kilometers on a side. The corners of the square were designated with permanent markers. Temporary markers were set up at intervals of 1-1.5 kilometers in a direction parallel to one of the sides of the square and 500 meters away. The seismologists marked out a central cross and prepared for seismic sounding. Then the radar sounding group on the STT-23 made a detailed survey of the relief under the ice. The seismic sounding group of the STT-21 studied the under-ice relief by the reflected wave method. The magnetologist on the ATT-52 did a magnetic survey of the test site. The geochemists and glaciologist dug bore pits and compiled a stratigraphic description of them. They took samples from the bore pits and cores from the well drilled by the thermal drill.

Construction Work

The 16th Expedition formed a construction brigade of 12 people to do construction work at Leningradskaya Station during the summer season of 1971-1972. This group was reinforced with four construction workers from the winter group of the 17th Expedition.

Other members of the winter personnel of the 16th and 17th Expeditions also took active part in construction at Leningradskaya Station. The work was directed by engineers P. S. Moskalev and E. S. Rusetskiy.

When the expedition arrived in the Leningradskaya Station region on 3 February the construction brigade began putting up wooden bridges over cracks in the fast ice and on the shelf along the unloading route. They built five bridges in all, two over cracks on the barrier and three on the fast ice. The most difficult was an inclined bridge across a widening crack 4-8 meters wide next to the barrier (see Figure 2 above). The erection of this bridge was made complicated by the fact that there was no fast ice next to the barrier, but only about three meters of snow. The lower support of the bridge was mounted on this small snow islet eight meters long by four meters wide. At first the contours of the islet could barely be discerned, but as cargo traffic moved across the bridge and tidal fluctuations occurred the cracks became sharply delineated and even opened up somewhat, so that they had to be covered with logs.

Cargo was lifted onto the barrier by a tractor pulling a 22-millimeter line 200 meters long, because deep concealed cracks were found on the sector of the barrier where the tractor was located. The barrier bulged considerably 20-30 meters from the fast ice along the axis of the lift and so the working line cut into the snow. Logs had to be dug into the snow every 5-6 meters perpendicular to the movement of the line to prevent this.

The lift operation was done as follows. Cargo brought in by the Ob' was unloaded 30 meters from the bridge. A team of hitch workers connected the load to the working line and the team leader gave a signal. The signalman on the barrier would receive it and transmit it to the tractor driver. Soon the working line pulling the load would begin rising onto the barrier along the axis of the bridge. In one month the entire cargo was moved to the station.

Construction work at Leningradskaya Station was begun on 1 March 1972. The site selected had fairly rugged relief, so first blasting had to be done, and then grading.

It was decided to combine the dining hall and dormitory in one building and the diesel room and garage in another to achieve a compact arrangement of facilities in the limited area. The single-module radio center building was set apart in view of plans to expand it to three modules (see Figure 6, next page).

However, only enough prefabricated slabs to form the bases for the pillars of three modules had been unloaded from the Ob', so it was necessary to begin welding these slabs from available materials. At the same time the installation workers prepared benches to assemble the frames and blocks of panels. The foundation pillars, heat insulation, blocks of panels, and frames of the six-module dining hall-dormitory building were installed in 14 days by a brigade of nine workers.

The dining hall-dormitory building was aligned and oriented on its site with due regard for the relief and prevailing wind. The building was set

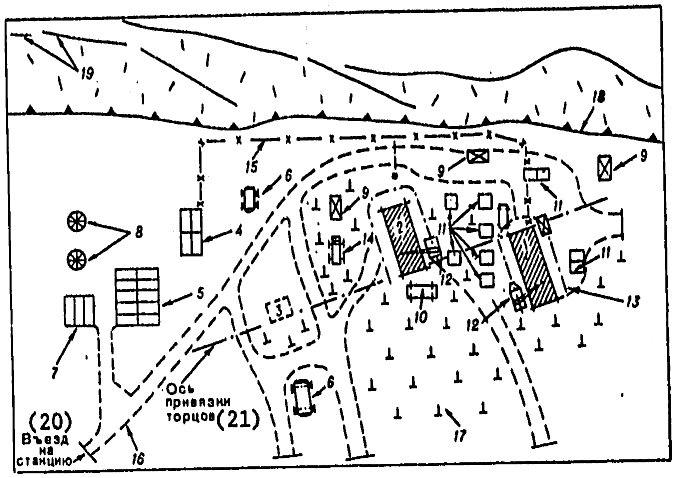



Figure 6. Master Construction Plan of Leningradskaya Station

Key: (1) Dining Hall-Dormitory (Under Construction);
(2) Diesel Room-Garage (Under Construction);
(3) Radio Center (Under Construction);
(4) Electric Power Plant;
(5) Existing Living Quarters;
(6) Fuel and Lubricant Storage;
(7) Magnetic Pavilion;
(8) Radio Towers;
(9) Temporary Structures;
(10) Panel Assembly Bench;
(11) Blocks of Panels for Buildings Under Construction;
(12) Truck Cranes;
(13) Crane Movement;
(14) Compressor;
(15) Temporary Electrical Grid;
(16) Transport Ways;
(17) Outcroppings of Bedrock;
(18) Boundary of the Crack;
(19) Snow Drifts;
(20) Entrance to the Station;
(21) Axis of Alignment of the Ends of Buildings.

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with its end slightly turned toward the primary wind and sufficiently raised above the terrain so that it is well ventilated from below and the trail behind the building has a gentle slope.

Construction of the diesel room-garage also began with grading work and driving 102.4-millimeter diameter pipe under the bases of the foundation pillars to a depth of 1.2 meters. The zero cycle was completed for three modules by the end of March, which made it possible to set up the crane immediately and start consolidated assembly of design elements for installation.

All outside installation work was finished by 20 April. Three diesel generators, a turning lathe, and two storage tanks were put in their places during installation of the frame. All the inside work in the diesel room-garage could be completed during the winter.

Drilling, installation of foundation pillars, and assembly of the frame of the radio center was underway at the same time. Construction of the center itself could not be started, however, because of delay in unloading building materials from the Ob'.

At Mirnyy a brigade of four persons worked from 24 December 1971 to 9 April 1972 constructing foundations for a wardroom and a services and residential building (see Figure 7 below) on Radio Hill.

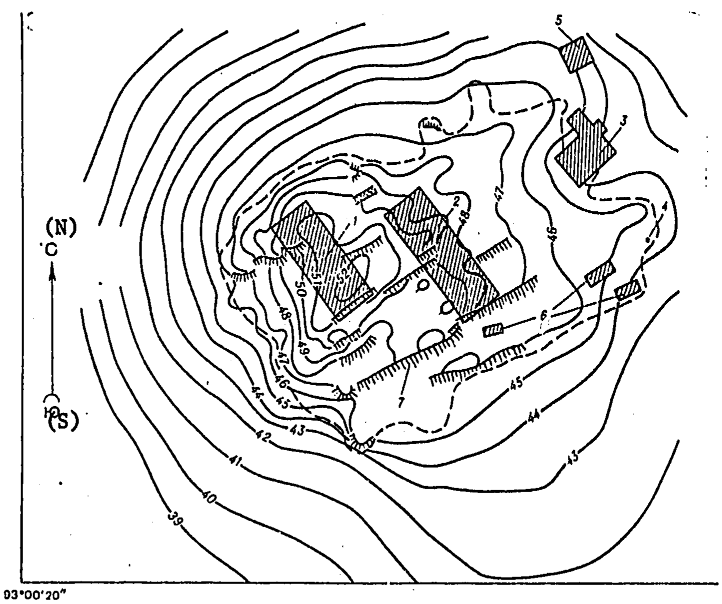


Figure 7. Construction Plan on Radio Hill at Mirnyy (Dotted Line Marks the Boundary of the Bedrock Outcropping)

Key: (1) Two-Story Services-Living Building (Under Construction); (2) Two-Story Wardroom Building (Under Construction); (3) Transmitting Radio Center; (4) Antenna Tower; (5) Storehouse; (6) Huts; (7) Precipices.

The brigade did the following jobs: excavated 599.6 cubic meters of rock by drilling and blasting; filled in 229.7 cubic meters of rock; drilled 202 meters of wells for pilings; drove 135 piles under pillars; electrical welding on 45 support platforms for the pillars.

The Work of Aviation

The aviation detachment of the 17th Expedition consisted of 83 persons: 57 flight personnel and 26 ground workers. The detachment was commanded by P. P. Moskalenko. The members of the detachment generally had a great deal of practical experience.

Two An-2 planes, spare parts, ground equipment, and 15 detachment members were loaded on the Navarin. The Ob' carried two An-2 planes, two Mi-8 helicopters, one Il-14 plane, spare parts, and 47 personnel. The Professor Vize carried 21 detachment members.

The Ob' arrived in the Molodezhnaya region on 18 December 1971. It took four hours 30 minutes to unload and assemble the two Mi-8 helicopters, six hours 30 minutes for the two An-2 planes, and 23 hours for the Il-14 airplane. After the planes and helicopters were broken in they began to be used in unloading the ship. The Il-14's that had spent the winter in Molodezhnaya and had been brought out of storage earlier were broken in at the same time. Work flights in support of the scientific groups began together with unloading the ships.

The Navarin arrived in the Amery Ice Shelf region on 15 December. Its An-2 plane was unloaded immediately and, after assembly and breaking in, began flights to find a place for the Amery Base runway. Then both the An-2's began unloading the ship. On 27 December the An-2's that arrived from Molodezhnaya joined the unloading and on 1 January 1972 the Mi-8 helicopters also began working on unloading the ship.

An air base and runway 2,000 meters long by 75 meters wide was set up on the Amery Ice Shelf to support the scientific work.

The decision to fly was made on the basis of a forecast compiled at Molodezhnaya and meteorological synopses received from the work parties. The flight control officer was G. V. Sorokin.

Flights were run from two runways at Molodezhnaya. D. I. Kozlov was the flight control officer. Flights at Mirnyy were made from a runway 1,200 meters long and 75 meters wide. V. A. Kartsev, of the 16th Expedition, was the flight control officer. Communications and flight control at Amery Base, Molodezhnaya, and Mirnyy were carried on by command and communications radio sets and short wave radio direction finders.

The unloading of the ship Ob' at Leningradskaya Station and the flights to Amundsen Sea were done by two crews (commanded by Yu. P. Matyagin and K. V. Karagodin) in one An-2 aircraft. The flights were made from ice fields alongside the ship. Communication with the aircraft was kept up by the ship radio.

The Ob' did not return to the region of Mirnyy and Molodezhnaya until May. Because of the complex ice situation all unloading was done by airplane.

During the period of work in Antarctica there were flights among the stations at Vostok, Mirnyy, Amery, Molodezhnaya, and Novolazarevskaya, scientific flights with aerial photographic surveying, magnetic, geological, and radar observations in the Amery and Molodezhnaya regions, and hunts for and checks on autonomous and magentic variation stations. In addition, planes were used for ice reconnaissance and unloading ships.

The total flying time of airplanes and helicopters supporting the work of the 17th Expedition was 3,298 hours 35 minutes. In this time there were 1,230 primary landings and the aircraft carried 1,526.75 tons of cargo and 1,233 passengers.

International Contacts

The 17th Soviet Antarctic Expedition maintained the tradition of friendly scientific contacts with the expeditions of other countries in Antarctica. There was regular telegraph and telephoto exchange of scientific information on meteorology, aerology, geomagnetism, seismic studies, and the ionosphere with foreign Antarctic stations.

The seasonal personnel of the expedition in the summer of 1971-1972 included 10 foreign scientists: two from East Germany, one each from Bulgaria, Hungary, and Romania, and five from Poland.

Friendly ties were maintained with foreign stations during the seasonal work of the 17th Expedition. For example, during the flight from Novolazarevskaya to Molodezhnaya on 21-22 December 1971 in an Il-14 piloted by M. M. Podol'skiy, Ye. S. Korotkevich, chief of the 17th Expedition, and V. G. Aver'yanov, chief of the winter group, visited the Japanese Showa Station. They were met by the personnel of the station led by Professor Oguchi, station chief.

On 2 January Ye. S. Korotkevich and V. G. Aver'yanov, flying in an Il-14 piloted by M. M. Podol'skiy, went from Amery Base to the Australian Mawson Station.

The Australians gave the Soviet representatives a cordial welcome, showed them the buildings of the station, and talked about the current work and plans for the future.

On 11 January a group of 23 American representatives led by D. Fletcher, head of American Polar investigators, flew to Vostok Station in a Hercules plane. The group included Secretary of the Navy Chafee, Shepard, the scientific head of McMurdo Station, Rear Admiral McCaddin, Senators Goldwater and Buckley, researchers, and representatives of American political and business circles. Ye. S. Korotkevich, chief of the 17th Expedition, was at Vostok Station during this group's visit.

Between December 1971 and March 1972 several maps of the ice situation in their cruise regions were transmitted to the Australian ship Nela Dan and the Japanese icebreaker Fuji. The maps were compiled at Molodezhnaya on the basis of satellite and aerial reconnaissance data.

Foreign ships stopped frequently in the roads at Bellingshausen Station. For example, on 18-19 February the station was visited by the Argentine ship Bahia Aguirre, carrying a group of Argentine observers traveling to Antarctic stations in conformity with the Treaty on Antarctica. Other visitors to this station were the Hero (U.S.), San Martin (Argentina), Lindblad Explorer (Norway), Arktik (West Germany), and Piloto Pardo, Elcho, and Lientur (Chile). The associates of Bellingshausen Station gave the crews of these ships traditional welcomes.

On 29 March 1972 the Ob' arrived in Littleton, New Zealand from Western Antarctica. One week before the ship arrived the New Zealand newspaper THE PRESS ran a notice of its scheduled arrival. On 30 March the same paper carried an interview with Ye. S. Korotkevich, head of the 17th Expedition, on the purposes and tasks of the Ob's voyage. Many people visited the ship and the ship's guest book contains many words of friendship addressed to our expedition members and the crew of the ship, as well as thanks for the hospitality. Robert B. Thomson, director of the Antarctic Service of New Zealand, visited the Ob' and left a note in the guest book with high praise for the cooperation between the peoples of the USSR and New Zealand in Antarctic work and a wish that the crew might have a successful further journey.

The American research ship Eltanin was moored in Littleton at the same time as the Ob'. A group of scientists from the marine detachment of the Ob' visited the American ship in response to a visit to the Ob' by the hydrobiologist of the Eltanin. The group inspected the Eltanin and familiarized themselves with its program of work.


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